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FIELD STRENGTH PREDICTION FOR VHF/UHF TERRESTRIAL BROADCASTING AND MOBILE RADIO SERVICES

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Summary

The propagation curves used internationally for the planning of services in the VHF and UHF Broadcast Bands are those of CCIR Recommendation 370 and associated Report 239. Derivations from these are also used for Mobile Radio planning in this frequency range. These curves, first produced some 30 years ago, have subsequently been the subject of somewhat arbitrary modifications and correction factors. The curves are essentially statistical in nature and require little detailed knowledge of individual path profiles except in the vicinity of the terminals.

Subsequently a number of organizations, including the BBC, have developed individual computerized prediction methods using terrain data bases. It seems probable that any replacement for the existing CCIR method should also follow this route, taking account of the increasing availability of such data bases, although also recognizing that for much of the world the density of such terrain data will be low.

The objective of the study described in this Report is three-fold. Firstly, the large amount of data available from broadcast surveys in the UK was used to assess and compare the accuracies of the existing CCIR and BBC prediction methods. Secondly, an attempt is made to develop an alternative simple prediction method, suitable in the first instance for use with a relatively coarse terrain data base, but capable of subsequent development and refinement if more detailed information is available. The new prediction method described here relies upon a classification of the propagation path according to whether it is line-of-sight, or has single or multiple diffractions. There are thus three basic propagation curves, common to all VHF/UHF Bands, together with a Band-dependent receiving angle correction curve. The results of this extremely simple method compare quite favourably with either the CCIR method or the much more complex BBC method.

Finally, the Report proposes a number of lines of further study which should lead to improved accuracy. Also, consideration is given to the impact of such a new prediction method on the relevant part (Section D) of CCIR Volume V.

Index terms: *Diffraction; CCIR; field strength; propagation; troposphere; UHF; VHF; prediction*

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1. INTRODUCTION

Since 1984 the BBC has been engaged on a study of VHF/UHF field strength prediction techniques which have been used for many years by the CCIR for broadcasting and mobile radio planning. They are described within Section 5D of Volume V of the CCIR Recommendations and Reports, specifically:

Recommendation 370	:	VHF/UHF Broadcasting Curves
Report 239	:	Propagation Statistics for Broadcasting
Report 567	:	Field Strength Estimation for Mobile Radio
Report 228	:	Measurement of VHF/UHF Field Strength

The BBC study had three main objectives:

(i) To review the accuracy of the CCIR predictions

(ii) To identify the scope for improvement

(iii) To provide evidence for any further propagation research work which may be required.

The investigation has been based mainly upon field strength measurements made by the BBC and the IBA during the development of their broadcast services. These have been obtained over the past 40 years; some were used in the construction of the original propagation curves from which the existing CCIR methods have emerged[1]. The CCIR curves of Recommendation 370 are based, for distances up to about 120 km, on median values of very large numbers of field strength measurements in built-up areas. At longer ranges, where temporal variations are evident, the data came from protracted experiments carried out at isolated and generally exposed receiving sites[2].

This study has concentrated upon the spatial variation of field strength, and for this purpose has used measurements made up to distances of about 120 km from transmitters where the effects of fading are relatively small. The measurements were obtained during site tests and surveys of about 25 broadcast stations, and also include some special investigations carried out to examine particular features, such as antenna height gain, polarization, multipath, and the effects of frequency.

The objectives of the study have been achieved; using a very substantial amount of measured evidence, the accuracy of the CCIR predictions has been determined, and the scope for improvement assessed. An extensive data base of field strength measurements has been established, combined with information describing the propagation paths to each of these measurement locations. This Report describes the work, the limitations of the existing prediction methods, and an approach to an improved method.

2. THE FIELD STRENGTH MEASUREMENTS

The BBC/IBA measurements used in the comparison came mainly from the service areas of stations shown in Table 1 and Fig. 1. Also listed are two parameters used in the CCIR prediction — height of the transmitting antenna above mean terrain (HAMT), and Δh — the latter giving some indication of the roughness of the terrain in each area. The statistics for these parameters were derived from an analysis of the individual paths for which measurements were made in a particular survey. For this reason dissimilar values occur when a station appears twice in the Table.

Also included, but not listed, were measurements from a number of UHF relay stations. These represent an important type of service for which the path lengths are generally too short to enable predictions to be made using the CCIR method described in Section 3.1. These measurements, comprising some 4750 additional paths, have also been included in analyses relating to the alternative prediction method considered in Section 7.3.

Three distinct types of measurement have been used. The first, employed for the Band I coverage assessment surveys, used a receiving antenna mounted at some convenient height upon the measuring vehicle; the receiving signal being chart-recorded whilst the vehicle was in motion. The output was subsequently corrected by the addition of a linear height gain, in order to give the field strength assumed to exist at the internationally accepted standard height of 10 m a.g.l. (for the earliest results using the Imperial scale of length, 30 feet). In this analysis the measurements recorded were the averages derived from the chart recordings over road distances of about 100 m. This represents about 15 to 20 wavelengths, and permitted

Table 1
Sources of field strength measurements

Band	Transmitter	Poln. H/V	HAMT (m)			Δh (m)			No. of paths
			Max.	**Mean**	**Min.**	**Max.**	**Mean**	**Min.**	
I	Ashkirk	V	358	311	163	489	152	45	428
	Crystal Palace	V	230	200	132	156	73	8	1,877
	Rowridge	V	250	231	155	188	55	0	1,413
	Tacolneston	H	158	152	145	65	37	21	627
	Wenvoe	V	344	327	255	413	125	0	1,488
II	Wenvoe	H	317	281	207	422	134	0	3,456
	Wrotham	H	306	239	177	179	95	21	3,557
III	Beulah Hill	V	235	210	101	168	72	7	3,422
	Emley Moor	V	477	412	233	345	137	27	1,720
	Huntshaw Cross	H	292	231	177	413	85	27	230
	Ridge Hill	V	302	264	209	241	89	13	445
	Winter Hill	V	597	551	368	361	100	23	1,475
IV	Bressay	V	300	280	246	195	67	0	589
	Eitshal	H	343	302	229	402	66	0	545
	Knockmore	H	432	299	207	275	119	11	299
	Skriaig	V	445	358	273	383	109	0	478
	Torosay	V	478	446	243	411	80	0	436
	Wrekin	H	387	368	293	349	71	12	3,854
V	Bluebell Hill	H	205	184	102	136	81	21	827
	Crystal Palace	H	307	285	233	149	56	7	628
	Sutton Coldfield	H	320	285	243	215	84	10	3,369

the effects of standing waves and local obstacles to be determined.

The second type of measuring technique, used in general for the Band III surveys, consisted of clusters of five 'spot' measurements, made with the receiving antenna elevated to 10 m above ground level (a.g.l.)[3]. The measurements in each cluster were separated by four or five metres, again to give an indication of the effects of local obstacles and of the standing wave ratio. A variation of this was the third method, adopted at UHF, which consisted of single measurements with the antenna at 10 m, the horizontal standing wave variation being occasionally assessed by small movement of the vehicle whilst the antenna was at the measuring height[4].

In addition to the measurements detailed above, many hundreds of town 'median' results were used, these being derived from individual results obtained within selected urban areas.

The total number of samples used is indicated later in the Report, when specific aspects of the study are described. It should be emphasized that the measurements were carefully selected from the substantial records still retained by the BBC and IBA, and considerable care was taken to ensure that they were reliable. The important question of accuracy of measurement is discussed in Section 3.3 of this Report.

The structure of the data storage used for the measurements is described in Appendix 1.

3. THE PREDICTIONS

3.1 The CCIR method

The CCIR prediction methods discussed here are all contained within Section 5D of Volume V of the CCIR Recommendations and Reports. The basis forms the major part of Recommendation 370, which gives a series of VHF/UHF field strength/distance curves. The curves were derived originally from a

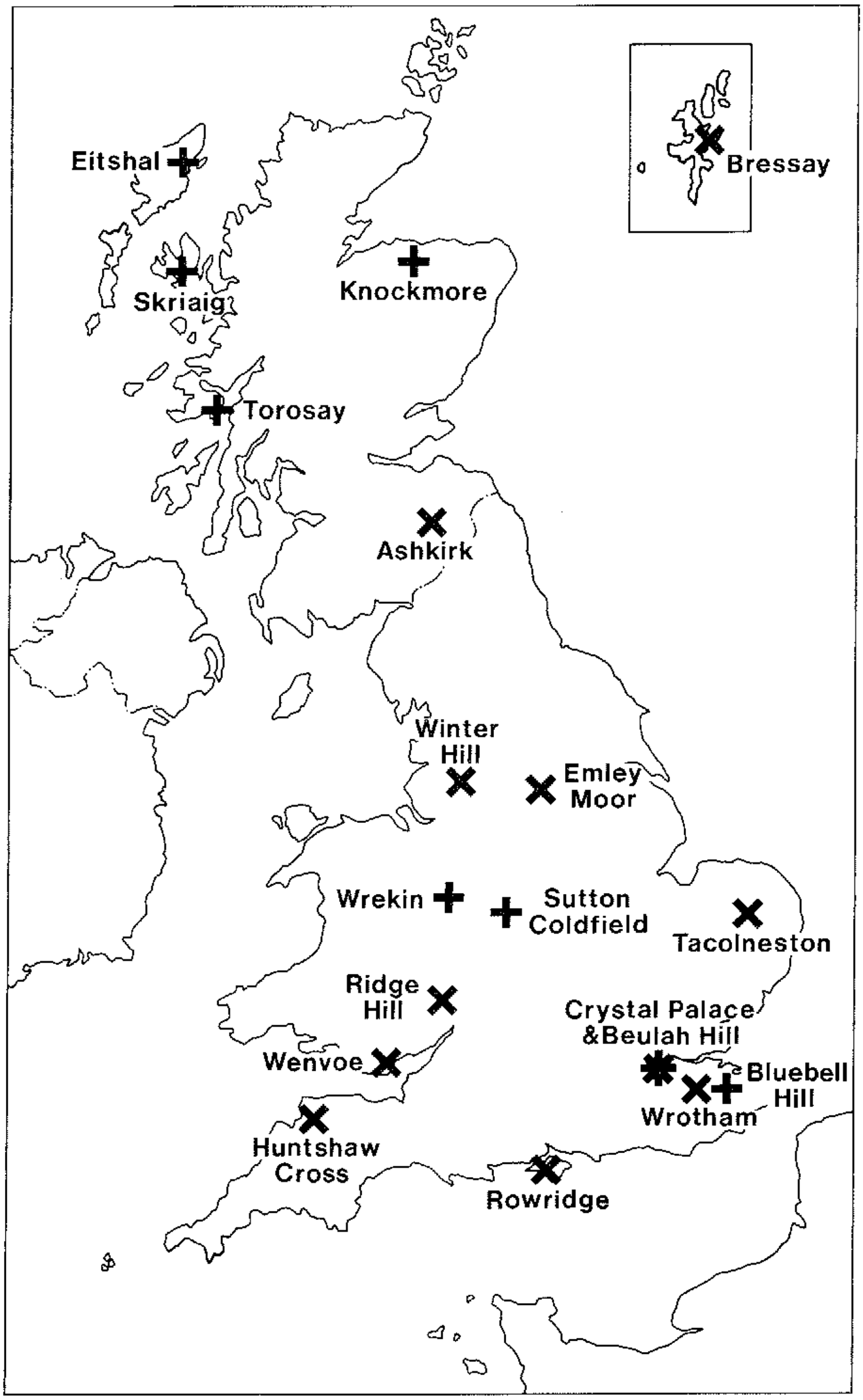


Fig. 1 - Location of transmitters listed in Table 1.

similar series produced for the ITU Planning Conference held in Stockholm in 1961. A typical example is shown in Fig. 2.

The results are based, for distances up to about 120 km, on median values of measurements in urban areas, through which 'best-fit' curves were drawn. In this, the techniques of Section 5D differ substantially from prediction methods proposed elsewhere in the same CCIR volume, where the objective is generally to predict the field strength at a precise point in space, such as may be required for a point-to-point link. In these cases, detailed information is usually made available concerning the nature of the propagation path (e.g. terrain data) and a relatively lengthy prediction is required which often makes use of complex theory. Intended for broadcast and mobile planning work, where many hundreds of thousands of

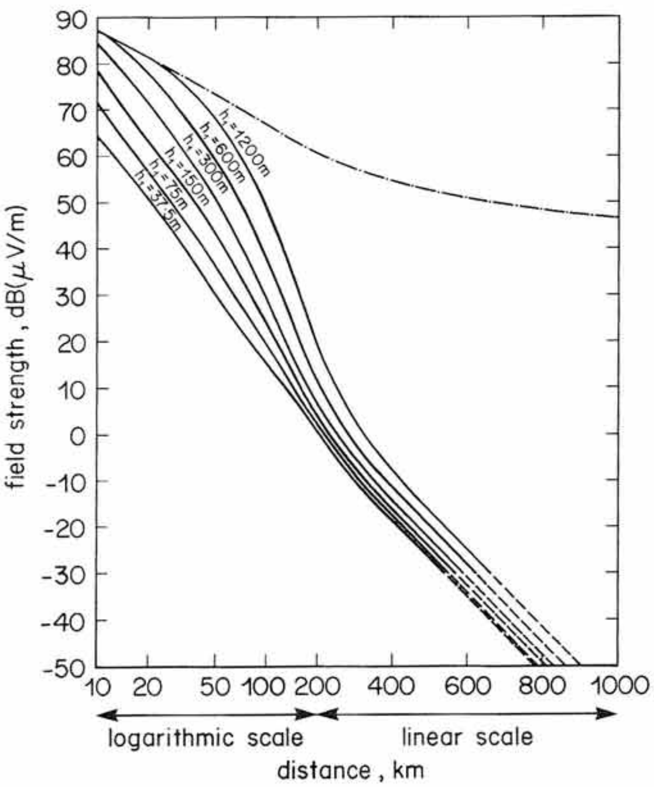


Fig. 2 - Example of propagation curves contained in CCIR Rec. 370.

paths have to be investigated, the 'statistical' methods adopted in Section 5D are far simpler but at some loss of precision.

The curves depict the decay of field strength with distance, and two simple parameters allow for adjustments to be made to take account of transmitting antenna height, and terrain roughness. The former is measured in terms of the 'effective height above mean terrain', i.e., the altitude of the transmit antenna above the mean level of the transmission path between 3 and 15 km from the site. In the basic propagation curves, the height of the receive antenna is always assumed to be 10 m a.g.l. Terrain roughness is measured by the Δh parameter, this being the interdecile range of the transmission path profile between 10 and 50 km. The datum of the curves is 50 m, this being the Δh value assumed representative of the type of terrain from which the mass of the original contributing measurements came, i.e., the gently undulating terrain found in much of North-western Europe and the USA.

The curves represent the field strength values exceeded at '50% of the locations'. Distributions, assuming a log-normal variation about these values, are evaluated in the Recommendation.

The curves are published for various percentages of time, namely 50%, 10%, 5% and 1%, revealing the effect of temporal variations on the longer paths. Wherever possible in this study, field strength variations with time have been taken into account in the analysis of measurements. Fading, as distinct from fluctuation caused by small movement of the terminating antennas, or reflections from some intervening surface, has been perceived for ranges as small as 30 km.

The curves of Recommendation 370 are also shown for various types of path (i.e. land, and different categories of sea); propagation over the latter, of course, is substantially influenced by temperature. Over the past ten years or so there has been much modification of the CCIR curves to incorporate new information which has emerged in this connection. This has arisen because measurements have been made in lower latitudes than those from which the earliest results came.

An accompanying report in Section 5D — Report 239 — provides additional data concerning the construction of the basic curves. It also contains individual reports on how greater precision may be achieved. For example, the receiver terrain correction is described, which achieves improvements by taking account of the nature of the terrain near the receiving site. Similarly, methods for predicting propagation over mixed land/sea paths are included, and information is also supplied to permit estimates to be made for receiving antenna heights other than at 10 m a.g.l.

An important feature to note about the curves of Recommendation 370, is that they do not permit predictions to be made for path lengths less than 10 km. If the receiver terrain correction of Report 239 is included, then, in principle, this minimum distance is extended to 16 km. This represents a significant constraint on the use of the method because it precludes predictions for most low-power stations.

Further data concerning reception at lower heights is contained elsewhere in CCIR Section 5D, in particular in Report 567, which deals with field strength estimation for mobile radio. Propagation curves predicting values at receiving antenna heights of 1.5 and 3.0 m a.g.l. are given, together with information describing some of the effects of polarization, vegetation and building losses.

The fourth CCIR report in Section 5D of interest to this study is Report 228, which nominally deals with the measurement of field strength, but which also contains information concerning the presentation of results. Although not specifically related to prediction, work undertaken in this study has a substantial bearing on this material.

3.2 The BBC method

Although the primary objective was to investigate the accuracy of the CCIR prediction techniques, the opportunity was also taken to compare the measurements against the BBC method, which has been in use over the past 20 years or so; it is typical of the more detailed field strength predictions which are being developed by several organizations. These call for a high density of terrain data in order to describe the unique features of each profile, and thereby estimate path losses, using various diffraction theories. The technique was originally devised for use at UHF — to assist with the implementation of the plan for a four-programme television network in the UK using these frequencies[5].

The terrain data base uses a 0.5 km grid of the UK, but the program has the facility to accept greater detail, e.g., directly from a map, in which case the profile is modelled on points interpolated at 0.1 km intervals. Each unit of the basic grid contains a ground height representative of the square, and certain clutter (building and tree) information. The accuracy of a data base of this density, and the ability of the software to reproduce a good model of the profile, is discussed later in this Report.

Given the locations of the terminals on each path, the terrain profile is extracted, and the first part of the program produces a simple geometrical approximation of this, permitting the use of an existing calculation technique. The most obvious approximation for a diffracted path is an assumption that it consists of a number of knife edges; the technique adopted is based upon the method of Deygout[6]. Investigation showed that where multiple edges are concerned, this overestimates the field strength. The second part of the program approximates the diffracted profile to a smooth surface having a rounded shape, after the method of Rice *et al*[7]. This produces an underestimate, and an empirical interpolation between the two profile models is then derived, to give a satisfactory final result.

3.3 Accuracy of measurements and predictions

Throughout this Report the 'accuracy' of a prediction is expressed as the ratio prediction/ measurement (in dB). In effect, it reveals the ability of the particular prediction to take account of the influences which determine the field strength. Although there can be little argument that measurement is the most reliable means of determining the field strength at a precise point in space, the values recorded and used in service area assessment — such as those which have been assembled for this study — are themselves certainly subject to error as reported in Appendix 2.

A most important source of 'error', the effect of which can substantially exceed those described in Appendix 2, occurs when the measured results are interpreted and maps and tables are produced to describe the coverage. The locations for measurements in the survey or site test will have been chosen to investigate conditions in a densely populated area perhaps, and/or to examine the effect of obstacles in the propagation path. In presenting the overall result, the engineer must relate field strength and terrain, so that a realistic forecast of coverage can be deduced from what is inevitably a very limited sample of measurements. This study has dealt with the actual measurements, so these potentially serious errors of coverage interpretation are not involved. But since field strength varies with small movements of the terminal antennas, what do the individual measurements represent? How precise are they, and what can a prediction technique reasonably be expected to estimate? In providing a datum for comparison it is essential to have these questions clearly answered; to do this, it is necessary to list the factors which will influence each measurement:

(i) Extent of the local standing wave in the horizontal plane of the receiving antenna.

(ii) Effect of vertical movement of the antenna.

(iii) Local clutter.

(iv) Terrain obstacles in the propagation path.

(v) Frequency and polarization.

In this study it has been assumed that the individual measurements are the median values of the local standing wave — (i) above. It is postulated that a prediction technique should be capable of estimating the general effects of the remaining factors (ii) to (v); but it could not, except under very simple circumstances, such as antenna calibration conditions, give a reliable result for a point in space. Nevertheless, as a preliminary it is useful to report the extent of the variation of (i), as revealed in this investigation.

In Section 2, it was described that most of the VHF results were the average values recorded over 10 to 20 wavelengths. Some early UHF surveys and experimental measurements provided similar evidence at the higher frequencies. As described, this is a distance sufficient to detect the standing wave situation and the scatter caused by local obstacles, but is generally inadequate to reveal major changes in the level of the terrain along the propagation path. To report the extent of the variations about the recorded average values, samples of the evidence were re-examined. To minimize the influence of local building losses, these were taken from measurements made at flat, open sites. The results produced distributions having the standard deviations (σ) shown in Table 2.

Table 2
Standing wave variation - standard deviations

Frequency	Ht. of Rx. Ant. 5 m	10 m	Directional/ Non-directional Rx. Ant.	H.P. dB	V.P. dB
Band I	X		Non-dir.	2.5	2.0
Band II	X		Non-dir.	2.0	
Band II		X	Dir.	2.5	
Band III		X	Non-dir.	3.0	2.0
Band IV	X		Non-dir.	3.5	2.5
Band IV		X	Dir.	3.0	
Band V		X	Dir.	4.0	

The results give some indication of the overall variation of the signal for small movements of the receiving antenna. They provide some data concerning the extent of error of an isolated measurement, assuming a normal distribution, whose limits can be inferred from its standard distribution. In practice, the distribution of results was negatively skewed, there being a higher probability of low values, as expected.

It is interesting to note the comparatively small difference between the standing wave ratios at these flat, open sites despite the range of almost 20 to 1 in frequency. In fact, the influence of frequency is likely to be even less than that shown, because the use of a directional receiving antenna for Band I might be expected to increase its ratio, due to the reduction in the measurement of reflected components. In the case of chart recording it was noted that results (taken from normal surveys) screened the true extent of the variation, due to the speed of the vehicle. The recording circuit was unable to reproduce the full excursions of the signal, so the results reported in Table 2 have been taken from slow-speed checks in open country.

4. COMPARISONS — CCIR PREDICTIONS WITH MEASUREMENTS

4.1 Urban medians

The first comparison reported here is that between the results obtained using the curves and corrections of Recommendation 370, and the median values of measurements in built-up areas. Depending upon the size of the area involved, the number of individual measurements used to deduce these medians varies from two or three up to several hundred. Because the curves were originally based on these measurements, and use of the median value excludes the extreme values measured in each case, it is to be expected that this comparison would reveal the least error. The results are shown in Table 3.

There is a relatively small sample for the UHF values in this Table. This results from broadcasters frequently using a technique intended to determine UHF field strength contours of specific value. For this reason, no attempt was made in the routine survey work to establish the median values in urban areas; the results are, therefore, limited to those obtained during early experimental work, before this measuring technique was adopted.

Table 3
Comparisons — CCIR prediction/measurement
Urban medians

Frequency Band	Sample size	P/M mean (dB)	Standard deviation (dB)
VHF	1,455	3.4	9.7
UHF	362	1.8	11.5

With reference to the VHF results, it has been suggested that an improvement in accuracy with the CCIR prediction might be realised if the present curves of Recommendation 370 could be sub-divided in terms of frequency. At present, they cover the range from 30 to 250 MHz, a ratio of more than 8 : 1 compared with the approximately 2 : 1 range of the equivalent UHF curves. The outcome of separating the results is shown in Table 4.

Table 4
Comparisons — CCIR prediction/measurement
VHF urban medians — by Band

Frequency Band	Sample size	P/M mean (dB)
I	660	5.5
II	254	0.8
III	541	2.0

This shows that whilst there may be a significant variation between the mean P/M ratios, these do not have any simple relationship with frequency. Moreover, caution is necessary in drawing any conclusions because of uncertainties associated with the receiving antenna height gain, used to correct the Band I and some of the Band II measurements. In Section 2, it was stated that all of the Band I results were made with the receiving antenna at some low height suitable for mobile measurement and a linear height gain was then added to produce 10 m a.g.l. values. Subsequent work suggests that in urban areas a greater correction should have been used. It would appear that the outcome of this would be to decrease the P/M ratio at Band I, and so decrease the argument for separation, but the situation is confused because the original UK data formed a substantial part of the evidence upon which the CCIR curves were based. It is not practicable at this stage to resolve the confusion; in view of this and other factors, no recommendation is made regarding sub-division of the present curves. It is felt that proposals offered later in this Report provide a better solution.

4.2 Individual results

The CCIR curves in Recommendation 370 represent the field strength values exceeded at '50% of the locations'. As described before, the majority of the values used to construct the curves, up to ranges of about 120 km, were extracted from measurements made in towns; no limit was imposed regarding the size or nature of these areas. Thus, at one extreme, a value may represent measurements made over a large city covering many square kilometres, at the other, it may have come from a few results obtained within a village of less than one square kilometre. Similarly, the area represented may be flat, or extremely hilly, with dense, high buildings, or with a few small cottages.

The only means of improving the definition within Recommendation 370, and so arrive at an estimate of the field strength at a precise point, is to use the curve depicting the ratio of field strength (for a given percentage of the receiving locations) to the median value; (Fig. 5 [VHF] and Fig. 12 [UHF] in the Recommendation). This is clearly not a very satisfactory approach, because it means that a subjective estimate has to be made of the 'percentage location' factor for a particular site. In fact, this correction is not intended to provide such information, but rather to give some statistical indication of how the field strength will vary over an 'area' (dimensions not defined). This is a fundamental weakness of the CCIR prediction which is discussed later; for this project, it was necessary to correct the CCIR 50% location results so that they could be compared with the individual measurements.

To obtain the detailed predictions, information contained in CCIR Report 239 was used; namely, the receiver terrain angle correction. This is determined by the angle θ between the horizontal at the receiving antenna and the line which clears all obstacles within 16 km of the selected receiving site; it is applied to the value already obtained from the appropriate propagation curve. The result is the most precise answer that can be given by CCIR Section 5D for an estimate of field strength at 10 m a.g.l.

Table 5 gives the result of comparing all the measurements with the basic Recommendation 370 prediction; i.e., in the absence of the additional precision afforded by the θ correction. To obtain the results shown in the Table, only the basic correction factors have been used in applying Recommendation 370; i.e. height above mean terrain, terrain irregularity (Δh), and the mixed path interpolation where necessary. In applying the Δh factor for paths less than 50 km in length, the height calculated is the interdecile value between a point 10 km from the transmitter and the receiving location. This modification has been incorporated to avoid including terrain which does not form part of the propagation path under consideration.

Table 5
Comparisons — CCIR prediction/measurement
All results (no θ correction)

Frequency Band	Sample size	P/M mean (dB)	Standard deviation (dB)
I	5,833	3.4	7.5
II	7,013	−0.2	11.7
III	7,292	2.9	11.1
All VHF	20,138	2.0	10.6
IV	6,385	3.2	14.3
V	5,984	−1.5	12.9
All UHF	12,369	0.9	13.8

The first observation to be made on the contents of Table 5 is that the mean results are remarkably good. There is definite evidence of a positive bias; i.e., the predictions are generally high, endorsing the trend in Table 3. The scatter of results about the mean has increased, although not as much as expected; indeed in the case of Band I, this is surprisingly low. This emphasises that local terrain and clutter effects — not taken into account with the prediction in this simplest form — becomes significant at frequencies above Band I.

The results of Table 5 should be improved by using the receiver terrain correction θ. Table 6 shows the outcome, which, with the exception of Band I, suggests an over-correction; i.e., the receiver terrain angle θ is introducing too much additional attenuation. However, there is a significant reduction in the scatter of the results, indicating that the approach is correct, but requires review.

It may be seen from Table 6 that the standard deviations increase with frequency. Whilst this is not surprising, note that if the predictions for the UHF Bands are carried out, using the VHF field strength curves (with UHF Δh and θ corrections), then the standard deviations for both Bands IV and V are reduced by 0.8 dB. Use of the VHF curves also makes the mean P/M ratio more positive by 2.2 dB for Band IV and 3.2 dB for Band V. These improvements are attributable to a feature of the CCIR method; while reasonably accurate over short distances, it progressively underestimates field strength for greater path lengths. Use of the VHF curves partially compensates for this, as indicated in Fig. 3(a), which shows mean P/M ratios as a function of path length in 10 km increments.

Table 6
Comparisons — CCIR prediction/measurement
All results (with θ correction)

Frequency Band	Sample size	P/M mean (dB)	Standard deviation (dB)
I	5,833	−0.6	6.5
II	7,013	−5.8	7.9
III	7,292	−1.4	8.1
All VHF	20,138	−2.7	7.9
IV	6,385	−1.1	10.7
V	5,984	−5.0	10.8
All UHF	12,369	−3.0	10.9

Fig. 3(b) shows the corresponding relationships between path length and mean P/M ratio for the VHF Bands. It may be seen that, with the possible exception of Band II, this path length dependence is much less than at UHF. In the derivation of Fig. 3, only paths with less than 25% oversea have been considered.

A possible explanation for this discrepancy between VHF and UHF is that the UHF measurement data may be biased as a result of having been obtained from coverage surveys. At the greater distances there will have been a tendency to carry out measurements only in those areas where a service is provided, i.e. under conditions where the overall path profile is favourable. This bias may be somewhat less pronounced at VHF.

During the course of the study, it was apparent that in a substantial proportion of cases, where the angle to the obstacle exceeded 1.0° above the horizontal, the obstruction was within 5 km of the receiving site. This prompted an investigation into the use of the correction, based upon the value of θ obtained within that range, rather than 16 km. This resulted in a substantial saving in data processing time, and allowed predictions to be made down to the minimum range (10 km) of the basic propagation curves.

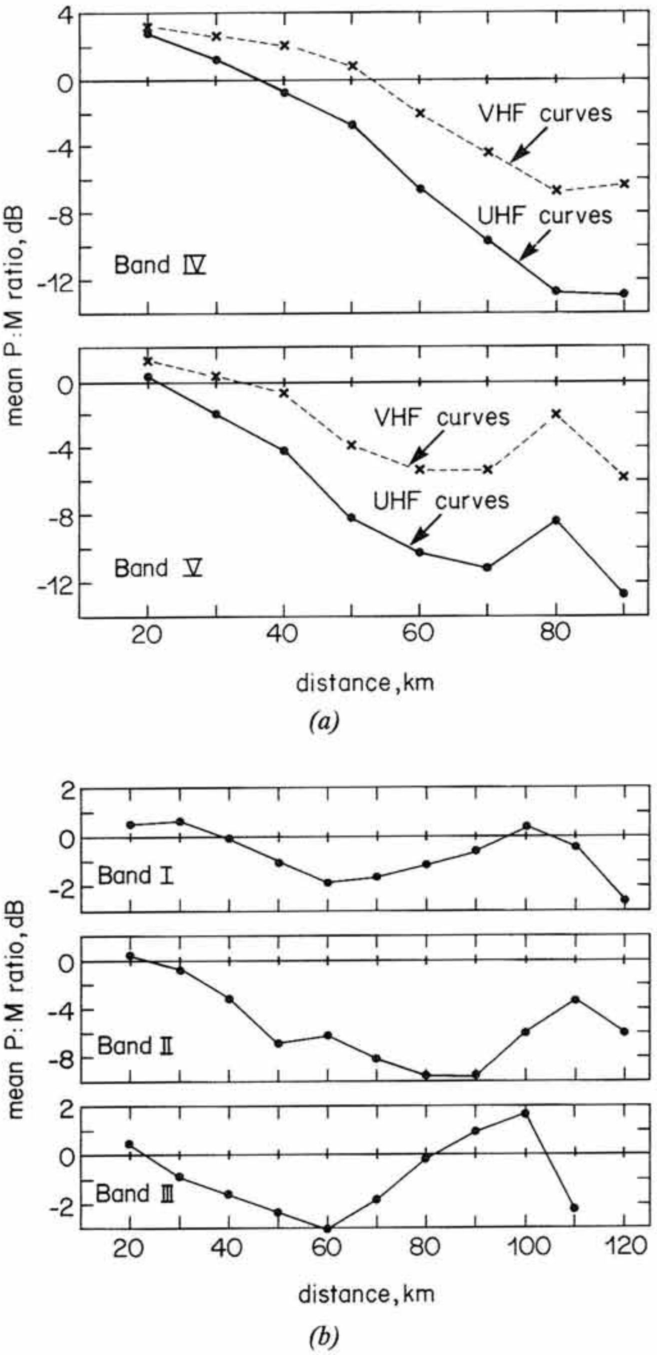


Fig. 3 - Prediction : measurement comparisons for CCIR method as function of path length:

(a) For Bands IV and V.

Comparisons have been carried out using both the UHF and VHF propagation curves of Rec. 370.

(b) For VHF bands.

The result is shown in Table 7, and it will be seen that whilst there is a slight deterioration in the degree of improvement assessed using the standard deviation as a measure, the mean values, certainly in the case of UHF, have improved. The correction curves used for this phase of the study were those designed for 16 km, as described in Report 239; they were not a revised edition for the shorter distance. Having regard to this, a study was carried out to see whether a worthwhile improvement could be obtained by such a revision.

Table 7
Comparisons — CCIR prediction/measurement
All results (with 5 km θ correction)

Frequency Band	Sample size	P/M mean (dB)	Standard deviation (dB)
I	5,833	1.4	7.1
II	7,013	−3.9	8.3
III	7,292	1.1	8.5
All VHF	20,138	−0.6	8.4
IV	6,385	3.4	12.6
V	5,984	−1.3	11.7
All UHF	12,369	1.1	12.4

Early results, using a limited number of samples, confirmed that an improvement in the P/M mean resulted from changing the slope of the correction curves. This distinguished the effects of frequency at angles more negative than −1°; a result confirmed for Bands I and II when the full data was examined. However, results for the other bands were inconclusive. Disappointingly, the modifications did not show a significant reduction in standard deviations for any frequency. It is considered that any required correction to the P/M mean can be more simply obtained in another way, with no modification to the existing θ correction curve being identified at this stage (as a consequence of the proposal to reduce the range of its determination from 16 km to 5 km).

5. COMPARISONS — BBC PREDICTIONS WITH MEASUREMENTS

Most of the errors, inherent in the CCIR prediction, can be attributed to the inability of the technique to take sufficient account of the terrain along the propagation path. As mentioned in Section 3.2, communications authorities in some countries have developed more accurate methods using large terrain data bases; the BBC prediction method[5] is a typical example.

As the BBC prediction relates to specific paths, with both terminals identified, its accuracy can be compared with the CCIR results shown in Table 6. Table 8 shows the basic comparisons between the BBC results and measurements.

To facilitate direct comparisons between this Table and those for the CCIR prediction method:

i) For Band I, in which the measurements were made at heights much lower than 10 m, the measurements were first scaled to 10 m on the assumption of a 'linear' height gain, before comparison with predictions for this height.

ii) In the main part of the Table, the analysis is restricted to paths longer than 16 km. However, for both Bands IV and V, the data base contains a substantial number of paths between 5 and 16 km in length. The values in parentheses are the results if these additional paths are taken into account; they are the relevant values for comparisons with the results from the alternative prediction method, presented in Tables 14 to 16 of Section 7.3.

Compared with the CCIR method, the BBC prediction gives a better result at most frequencies, as confirmed by the smaller standard deviations. The inclusion of the additional short range measurements improves the mean prediction error (implying that for these paths the prediction must overestimate the field strength) but worsens the standard deviations.

The BBC method was first developed for UHF. When adapted for VHF, the parameters were optimized on the basis of Band II data only. It is, therefore, not surprising that the P/M mean and standard deviations, for Band II in Table 8, are slightly lower than for either Bands I or III. Interestingly though, the less positive P/M value for Band II is consistent with Tables 4 - 7. These, in turn, are supported by the results of a study (unpublished) of

Table 8
Comparisons — BBC prediction/measurement. All results

Frequency Band	Sample size	P/M mean (dB)	Standard deviation (dB)
I	5,833	3.9	7.0
II	7,013	1.3	6.8
III	7,292	3.1	7.4
All VHF	20,138	2.7	7.1
IV	6,385 (9,828)	−2.0 (−0.7)	9.7 (10.5)
V	5,984 (8,288)	−4.2 (−2.9)	9.3 (10.0)
All UHF	12,369 (18,116)	−3.1 (−1.7)	9.6 (10.3)

comparisons between measurements of transmission in the three Bands, carried out at each of three transmitting sites; they showed field strengths in Bands I and III to be similar, but lower than for Band II.

A closer examination of the BBC results is informative; Table 9 gives the results of analysis in which the propagation paths have been categorized in terms of the number of obstructions.

Table 9
Comparisons — BBC prediction/measurement by path category

Path category	Sample size	P/M mean (dB)	Standard deviation (dB)
VHF			
Clear	4,291	4.4	5.9
One obstacle	7,123	2.3	7.3
> One obst.	8,785	4.9	8.6
UHF			
Clear	5,305	0.2	9.5
One obstacle	5,616	−5.6	9.0
> One obst.	1,448	−3.8	9.0

The overestimation at VHF is again revealed, with the greatest errors obtained for the paths containing more than one obstacle. The error is especially severe at Band I, where the P/M mean value is +9.6 dB, with a standard deviation of 7.8 dB. It is likely that ground reflection at the lower frequencies is a serious source of error; failure to deal with this results in the overestimate at VHF, especially for Band I.

At UHF, where ground reflection is incoherent, the results for clear paths are noticeably better than those for VHF. However, with the exception of single obstacle paths at VHF, the effects of terrain obstructions are not well defined, losses being underestimated at VHF, and overestimated at UHF.

6. OBSERVATIONS ON THE PREDICTION METHODS

6.1 CCIR predictions

6.1.1 General

Apart from the inaccuracies inherent in the CCIR prediction, which arise as a result of oversimplified approximation of the propagation path, various other problems have been reported. This is not surprising, considering that the technique has been intensively used throughout the World for nearly 30 years. Certain problems and recommendations were identified in a report issued by IWP 5/5[8]; *ad hoc* adjustments have been made from time to time to correct some of the difficulties. Similarly, as new information has emerged, this has been incorporated where possible. Whilst the overall scope and contents of the predictions are now more comprehensive, the outcome of these various modifications has been mixed.

This section summarizes the situation, as perceived in the light of past developments and from the results of this project.

6.1.2 The basis of the CCIR propagation curves

Of prime importance is the basis of the curves and the nature of the data on which they are constructed. As they are based, at the shorter distances, upon urban medians, field strengths in open country (away from building clutter) may be expected to be greater than the values indicated by the curves. Another important factor, which affects the VHF curves, relates to the means of correcting measurements made with a receiving antenna at a height of less than 10 m a.g.l. The subjects of receiving antenna height gain and clutter loss are dealt with at greater length in Section 7 of this Report; at this stage it is only intended to describe the effect on the CCIR curves. Fig. 4, which is dimensionless, illustrates the points now discussed.

In respect of measurements made at heights of between 3 and 5 m a.g.l., checks were made to determine height gain, but the number of these was limited. For practical reasons most of these checks were carried out at comparatively open locations, away from buildings, and showed that in such areas a linear height gain was generally applicable (G_m). In presenting the results, this correction was used for both urban and rural measurements, thereby producing the values assumed to exist at 10 m a.g.l., U_a and R_a respectively; the former being used to construct the curves.

Closer analysis of the small amount of early evidence, and of much recent measurement, has confirmed that in urban and suburban areas, the receiving antenna height gain exceeds the linear value. The early work suggests that the average in these built-up areas, for a 2 : 1 increase in height at VHF, is approximately 9 dB; though there are wide variations and this statement only relates to measurements made in the range 5 - 10 m a.g.l. Recent work on Band II by various experimenters confirms this analysis, although some of the evidence is conflicting.

In part this can be attributed to the type of receiving antenna used. As mentioned earlier, the

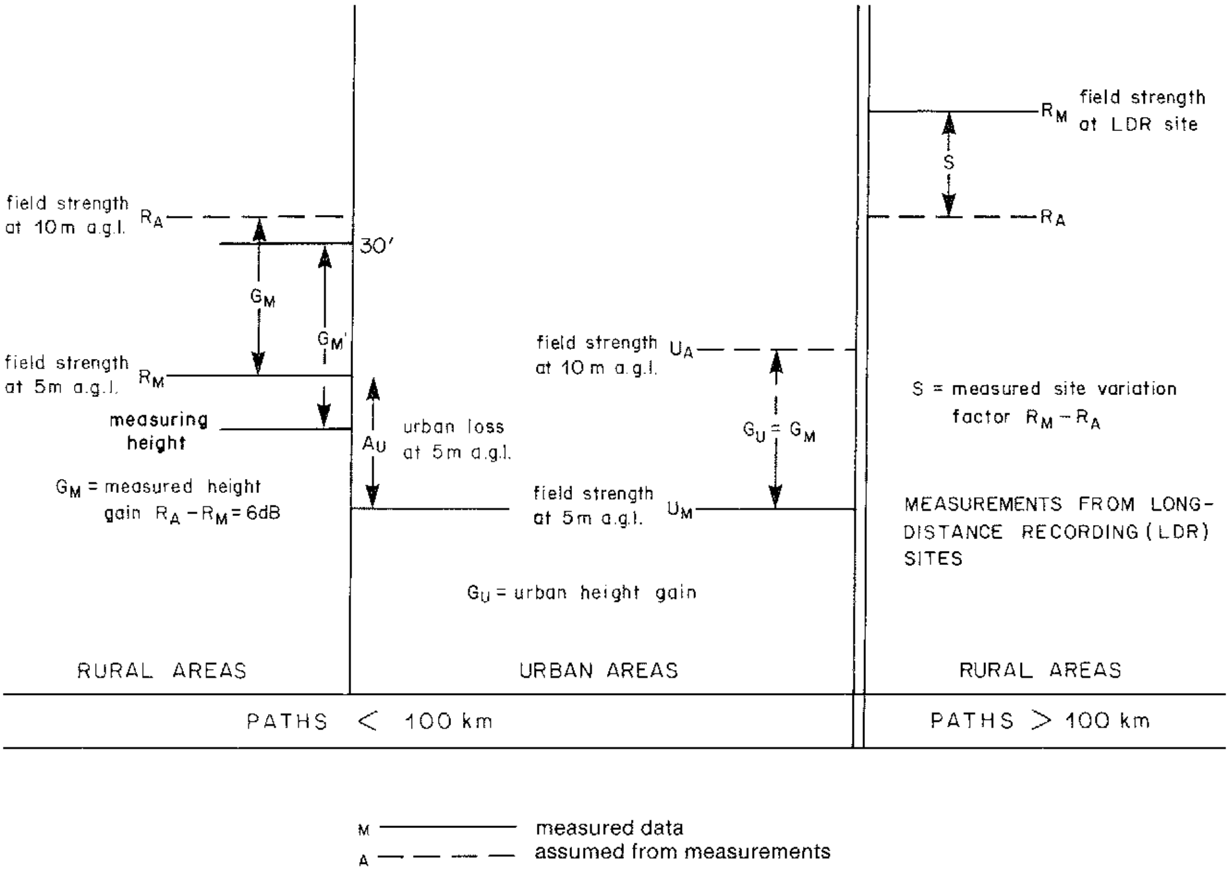

field strength at 10m a.g.l. R_A
30′
G_M
G_M′
field strength at 5m a.g.l. R_M
measuring height
G_M = measured height gain R_A − R_M = 6dB
A_U
urban loss at 5m a.g.l.
field strength at 10 m a.g.l. U_A
G_U = G_M
field strength at 5m a.g.l. U_M
G_U = urban height gain
field strength at LDR site R_M
S
R_A
S = measured site variation factor R_M − R_A
MEASUREMENTS FROM LONG-DISTANCE RECORDING (LDR) SITES
RURAL AREAS
URBAN AREAS
RURAL AREAS
PATHS < 100 km
PATHS > 100 km
M measured data
A assumed from measurements

Fig. 4 - Features of UK measurement data used in preparing propagation curves of CCIR Rec. 370.

non-directional antenna will tend to record higher levels of field in built-up areas where the direct signal is obstructed, and reflections are measured. The type of receiving antenna is also a significant factor when there is a requirement to extrapolate the results for some other height.

A further complication, that might affect those early BBC measurements which had been contributed to the CCIR, is that they were made at a time when the 'standard' receiving antenna height was 30 feet (9.15 m), shown as G_m' in Fig. 4. There are UHF measurements to show[9] that the height gain curve steepens as it passes the average roof height (about 9 m), at which point the antenna rises above local clutter.

In the light of all this evidence, it seems likely that the original VHF Bands I and II data contributed by the UK underestimated the field strengths existing at 10 m a.g.l. in urban areas.

Two other important points must be made regarding Fig. 4. These concern the definition of the datum of the curves and affect both VHF and UHF.

Firstly, it will be appreciated that the urban loss, A_u shown in Fig. 4, consists of clutter loss and attenuation caused by the local terrain. The latter is significant in the UK where most towns are situated in valleys and the effect on the curves of the base data has never been clarified. The present CCIR curves give no guidance in this respect. Other reports in CCIR Section 5D provide information concerning the effect of the local terrain and clutter losses, but the reference curves in Recommendation 370 are inadequately defined.

Secondly, and this is related to the point made in the previous paragraph, it is important to note the different receiving site datum used for measurements made at the greater distances (although these are not dealt with in this Report). These measurements came from long-distance recording (LDR) experiments, which were almost invariably conducted at exposed, open sites, with the receiving antenna at 10 m a.g.l. The measured field strengths (R_m) were corrected by site variation factors to produce results for the average rural terrain conditions in the locality of each site (R_a). There is thus an inconsistency in the datum along the length of the CCIR curves, in that at short ranges they are based on urban results, at longer distances they represent rural conditions.

The implications of these various incompatibilities in the curves for frequency planning work are mixed. Benefits in coverage achieved will occur because, whereas the longer range results are generally used to assess interference, they will overestimate the effect of this for the majority of the population, who tend to live in valleys, where the interfering signal will be attenuated, both by the local terrain and by clutter losses. Field strengths of wanted VHF signals at rooftop levels may have been underestimated. In these circumstances, power restrictions dictated by the CCIR curves may be unnecessarily stringent.

6.1.3 Height above mean terrain

In the CCIR prediction, the effect of increasing the height of the transmitting antenna is measured by the height above mean terrain parameter (HAMT). In Recommendation 370, propagation curves are given for a range of these heights, having octave relationships and extending from 37.5 to 1200 m.

In preparing the original curves, there was little evidence from the UK to support the full range of heights shown, because the majority of the results were confined to the range 200 to 400 m, as shown in Fig. 5.

Comparatively few results were available from other countries, and the effect of height outside this range was calculated assuming a smooth plane earth to exist between the terminals.

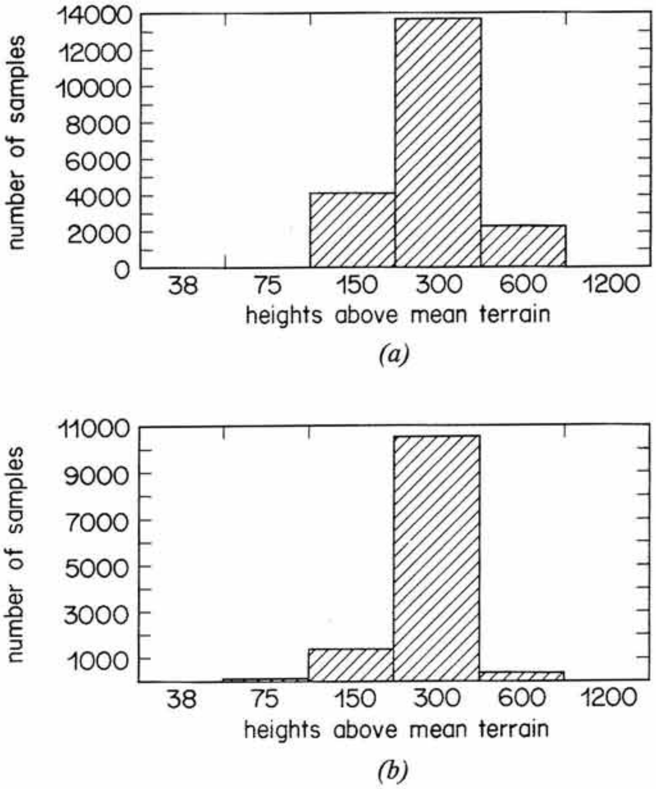


Fig. 5 - Histograms indicating ranges of effective transmitting antenna heights above mean terrain used in derivation of original CCIR Rec. 370 curves.

(a) All VHF transmitters *(b) All UHF transmitters*

An investigation of this height parameter, using the measurements now available, is not encouraging. Figs. 6(a), 6(b) and 6(c) have been produced by analysing **urban** measurements, made for overland paths at intervals of five kilometres from the VHF transmitters in the study, and for three heights above mean terrain — 150, 300 and 600 m. Medians have been calculated for each group, effectively producing a series of 'towns', each separated by 5 km along radials for the values of height above mean terrain quoted.

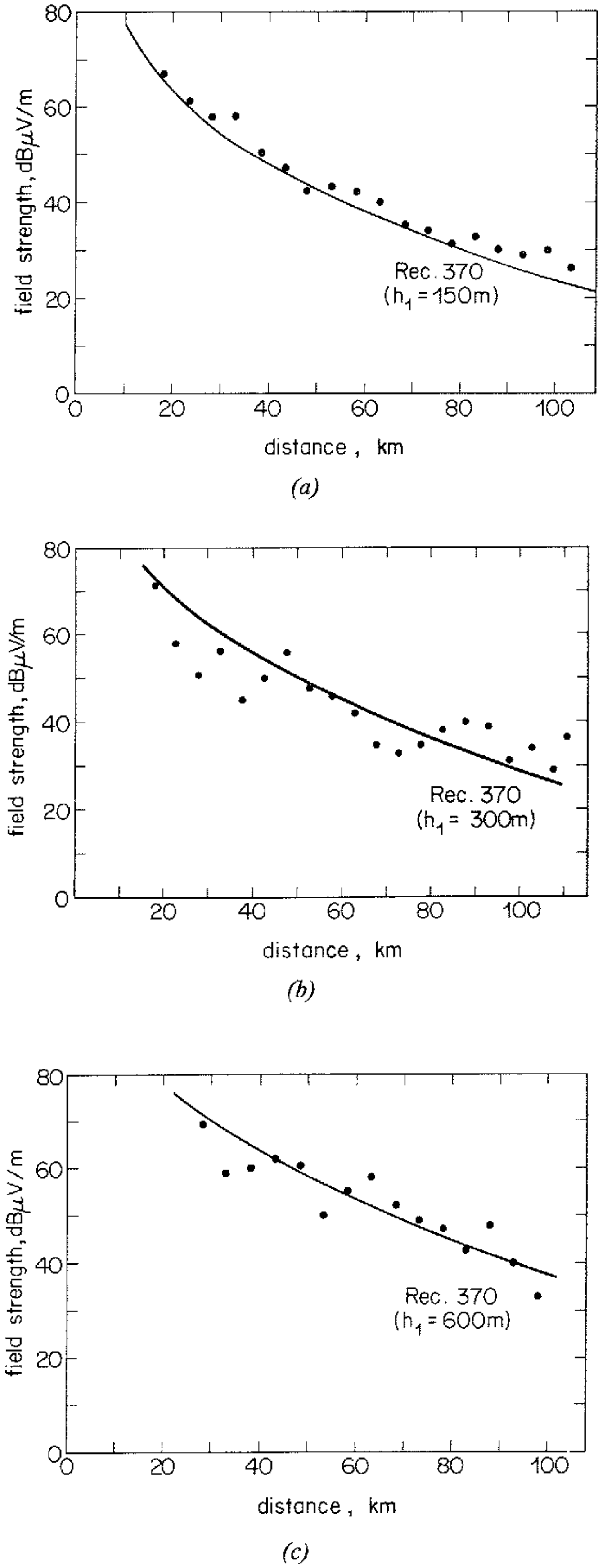
It will be seen that whilst the lowest height investigated — 150 m — gives close agreement between the CCIR curve and the measurements, with least variation about the theoretical values, results at the greater heights are poor. There is little difference between the actual 150 m and 300 m results, indeed at the shorter ranges there appears to be a height loss.

The full effects of ground reflection, more apparent at the lower frequencies, is obscured in this analysis by combining all the VHF measurements; although evidence of cancellation can be detected in individual results.

Further evidence, that a single parameter (based upon a limited part of the terrain along each profile) is inadequate, is demonstrated by the results in Figs. 7(a) and 7(b). In these, transmitting antenna height gain results, obtained during VHF site tests at the Crystal Palace station in London, have been plotted at 10 degree intervals of azimuth. The ordinate value is the height gain relative to the field strength measured when the adjustable transmitter antenna was at a height above mean terrain of 100 metres, for each interval of azimuth. About 100 height gain measurements have been used, each determined at selected receiving locations whilst the transmitting antenna was raised from a height of 8 m above the site to about 175 m. There is considerable variation along many of the radials, and a substantial difference from the theoretical figure suggested in each case by the CCIR curves. It is clear that height gain is determined by many features in the *overall* path, not just a part of it. It is seldom constant along its length, although this variation apparently decreases in flat terrain.

To some extent, this last feature is demonstrated by the correlation between the actual height gain and the site height, with respect to the level of mean terrain, as revealed by Fig. 8. In this, the gains for the height ratio 200 m/100 m and the site height, relative to mean terrain, have been plotted as a function of azimuth.

Further evidence at Band III, supporting the general conclusion that the parameter is inadequate, has been obtained from measurements made of the IBA/BBC transmissions from Winter Hill. Results are available for three transmit antenna heights above ground level — 37 m, 122 m and 241 m. Unfortunately, because the site itself is high (437 m a.m.s.l.), the apparent increase in height above mean terrain is small in many directions from the transmitter. However, an investigation of measurements in built-up areas, along radials where the height differences were approximately 170 - 250 m and 170 - 370 m, again revealed very significant differences from the CCIR prediction. Measurements were available for 36 areas where the height difference was 170 - 250 m, which



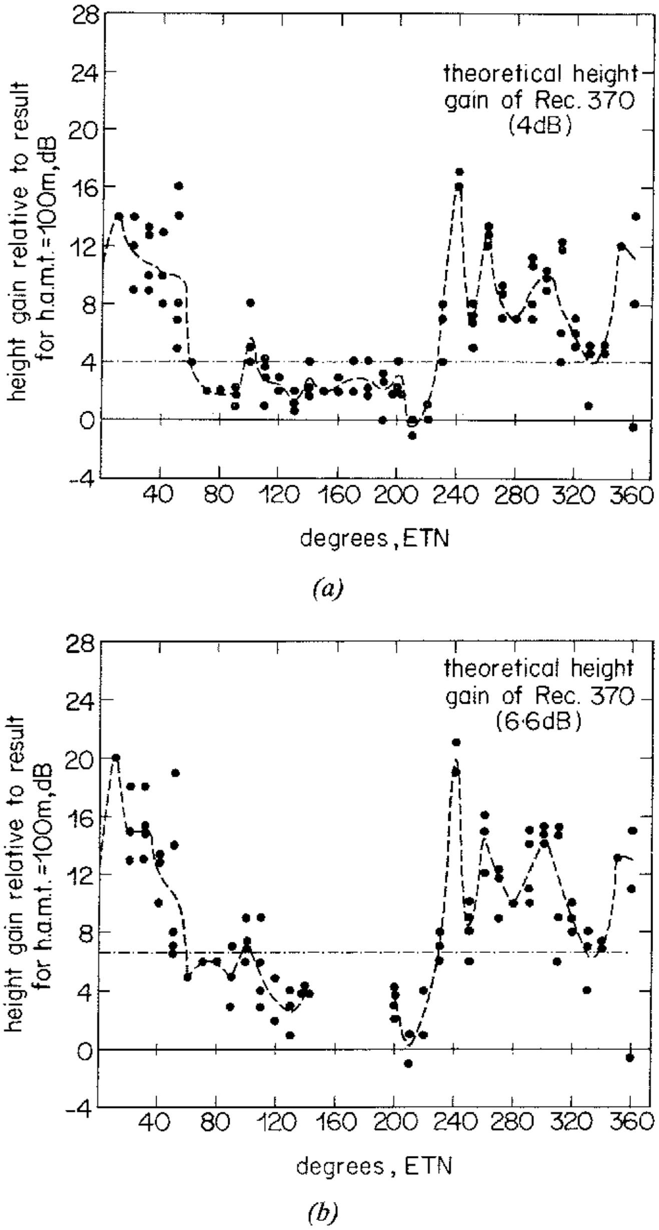
(a)

(b)

(c)

Fig. 6 - Comparison of VHF urban measurements with CCIR Rec. 370 curves for HAMT of:

(a) 150 m; (b) 300 m; (c) 600 m



(a)

(b)

Fig. 7 - Crystal Palace Band I site test: height gains as function of azimuth from:

(a) 100 - 150 metres a.m.t. (b) 100 - 200 metres a.m.t.

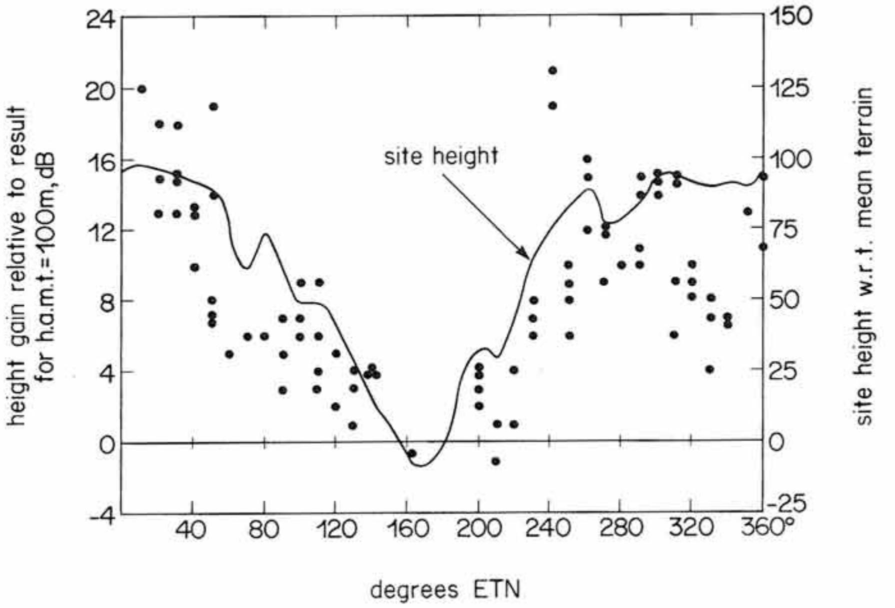


Fig. 8
Crystal Palace Band I site test: height gains (100 - 200 metres a.m.t.) and site height a.m.t. as function of azimuth.

should give a theoretical increase of 4 dB. This figure was exceeded in 19 areas, whilst 12 produced a lower value, and was equalled in five of the areas. In the case of the 170 - 370 m results, a theoretical increase of 7 dB should have been achieved. This figure was exceeded in 36 of the 61 results, 18 of the towns gave lower values; and seven produced the theoretical gain. As before, departure from the theoretical results was greatest where the transmitting site was well above that of the mean terrain.

It is concluded from the UK results that height above mean terrain is an inadequate means of measuring the influence of the altitude of the transmitting antenna.

6.1.4 Terrain irregularity factor, Δh

This parameter is specified in Recommendation 370 for the purposes of defining the effect of terrain irregularity. It is not intended for use at frequencies below 80 MHz, and indeed it was not used in the planning work associated with the Region 1 Band II (88.0 - 108.0 MHz) planning conference of 1982/1984, although the reasons for this were administrative and not technical.

The type of terrain in the areas from which the measurements used in this study are drawn, quantified by Δh, can be seen from the figures shown in Table 1. The average of all these UK results is 90 m, an interesting point bearing in mind that the 'typical' figure used as a datum in the CCIR curves is 50 m. However, the bulk of the UK measurements contributed at the time of the original formulation of the CCIR curves, came from the Crystal Palace transmitter, where the surrounding terrain on the evidence of that work produced an average Δh of 65 m.

The influence of this particular correction upon the accuracy of the CCIR prediction is mixed; this may be attributed to the way in which it was introduced. To trace this, reference must be made to the origins of the Recommendation 370 curves, namely the Technical Data for the Stockholm Conference[10], and certain subsequent issues of Volume V. For the Stockholm Conference, the correction was only used for UHF, it being reasonably stated that 'the influence of irregularities in the terrain is of greater importance in Bands IV and V than in Bands I, II and III'. It was subsequently extended to Band III[11] and then to Band II[12], although it appears this took place without a very detailed check of the overall implications.

The study which has now been completed underlines the fact that there is some conflict between the use of the Δh adjustment and the terrain angle correction, which was introduced independently. Table 10 shows the results of comparing the CCIR predictions with measurements, with and without the Δh correction but excluding the terrain angle. Table 11 shows the equivalent results, this time including the terrain angle correction.

Dealing first with Table 10, it will be seen that the application of Δh reduces the mean error in three of the four cases. Unfortunately, having regard to the decision taken at the Band II planning conference, almost the best result is obtained for those frequencies. There is a marginal reduction in the scatter of the predictions in three out of the four cases, but the main effect is to introduce additional attenuation and so produce a downward shift in the majority of the results. On the evidence of these results, it could be argued that the Δh correction should also be extended to Band I for consistency, because Table 5 indicates a

Table 10
Comparisons — CCIR prediction/measurement with/without Δh (no θ correction)

Frequency Band	Sample size	With Δh P/M Mean dB	With Δh Standard deviation dB	Without Δh P/M Mean dB	Without Δh Standard deviation dB
II	7,013	−0.2	11.7	4.0	12.3
III	7,292	2.9	11.1	5.5	12.1
IV	6,385	3.2	14.3	4.7	14.8
V	5,984	−1.5	12.9	0.7	12.7

Table 11
Comparisons — CCIR prediction/measurement with/without Δh (with θ correction)

Frequency Band	Sample size	With Δh P/M Mean dB	With Δh Standard deviation dB	Without Δh P/M Mean dB	Without Δh Standard deviation dB
II	7,013	−5.8	7.9	−1.7	8.1
III	7,292	−1.4	8.1	1.3	8.5
IV	6,385	−1.1	10.7	0.4	10.7
V	5,984	−5.0	10.8	−2.8	10.2

positive P/M ratio for Band I greater than that without Δh for Band II in Table 10.

Turning now to Table 11, here the results have taken account of the terrain angle correction also. Again, the inevitable outcome of using Δh is to reduce the mean without significantly affecting the scatter, but here, combined with the θ correction, the prediction substantially overestimates the losses. It seems likely that this is a result of the independent derivation of the two corrections, without taking account of their mutual influence, although full contributions to the CCIR on this subject have not yet been investigated. In the case of the UK — the source of the proposal for the original terrain adjustment — the correction was derived from UHF measurements in the Crystal Palace area. As mentioned above, the average Δh for the measurements, originally contributed for this station, is 65 m; it is believed that the VHF equivalent was based upon results in the same area. Although the range of Δh around the transmitter ranged from 20 to 130 m, the examination did not take account of this separate influence upon the result; primarily because the UK study into the use of a θ correction was looking at means of improving its own detailed prediction, which made no use of Δh. In this particular case, therefore, there is an apparent overlap between the two corrections in the CCIR prediction.

Comparison of the standard deviations in Tables 10 and 11, indicates that irrespective of whether or not the Δh correction is taken into account, introduction of the θ adjustment reduces the standard deviation and is thus an effective means of improving prediction accuracy. In view of the apparent overlap between the two, and the fact that in no instance in Table 11 does incorporation of Δh reduce the mean difference, it is questionable whether this correction factor should be retained when the θ correction is applied.

6.1.5 Location variation

The variation of the field strength with movement of the receiving antenna is not precisely stated in the present Section 5D. Within Recommendation 370, the ratio of the field strength for a given percentage of the receiving locations, to the median value shown in the curves, is shown in two figures of the Recommendation (5 and 12). These are log normal distributions and, in the case of UHF, only their extent is influenced by the appropriate Δh. These curves were derived from analysis of the 10%/50%/90% results of the field strength measurements made in populated areas; i.e., those used in the construction of the original curves.

The extent of the distribution about the median values can be attributed to many factors — features in the overall path, local terrain, clutter loss, receiving antenna height gain, polarization, the directivity of the receiving antenna, frequency and multipath. The disparate effects of some of these have been subsequently examined by many authorities; reports and proposals appear elsewhere in Section 5D, but comment here is confined to the Figs. 5 and 12 of Recommendation 370, which still remain in the texts. More extensive discussion is left until later when proposals are made for improvements.

Analysis of the measured data, from which the original results came, underlines the fact that the concept of log-normal distribution for the urban measurements is an oversimplification. It is a conclusion readily reached if the 10%/50%/90% values are plotted on arithmetic probability paper, and a best fit line produced. However, deviations from this distribution are extensive, and the assumption of log-normality, based on this form of appraisal, can lead to serious error in estimating the real dispersion in particular cases. It is also observed, that the CCIR figures refer to 'percentage receiving locations'. Distinction must be drawn here between 'locations' and 'population', because the measurements from which the results originally came, were distributed with regard to population density.

As with other features in Section 5D, better definition is required.

6.1.6 Mixed paths

Although the propagation path lengths of the measurements investigated in this Report were < 120 km, and were mostly overland, several hundred did pass over sections of sea. In particular, the Rowridge, Wenvoe and Winter Hill stations offer some oversea paths; results from these have been used to check the accuracy of the CCIR method for dealing with mixed path propagation, described in Report 239. Two approaches are offered in the CCIR texts; the one which has been used for the predictions in this Report is that described as Method A.

In order to assess the usefulness of Method A, against treating all mixed paths as if they were overland, a comparison was made of prediction/measurement errors for the mixed paths in each frequency band. For the purpose of this comparison, the only mixed paths considered were those where the difference between the mixed and overland path predictions was at least 2 dB. Such a selection process was considered desirable; this was to avoid the comparisons being unduly weighted by the relatively large number of nominally mixed paths, where an oversea component is small enough to make a negligible difference to the prediction. Moreover, the relative shapes of the oversea and overland propagation curves are such, that a simple parameter (e.g. percentage of path oversea) does not form a satisfactory selection criterion. The results are shown in Table 12.

It can be seen that in all cases the mixed path Method A calculation significantly reduces the mean prediction error. For all cases, except that of Band V, it also reduces the standard deviation.

For three of the five Bands, the mean error of prediction for the mixed paths is less than 1.0 dB. For the band showing the greatest error (Band III), the mixed paths were all from Winter Hill to locations on the North Wales coast. These paths were all from a high transmitting terminal, over a flat plain before crossing the coast, with most receiving locations on rising ground. It is, therefore, to be expected that measured field strengths would be higher than indicated by the simple prediction, as indicated by the negative P/M mean.

It is concluded on this evidence that the Method A is a satisfactory means, within the overall prediction, of treating these types of path.

6.1.7 Summary of comments on the CCIR prediction method

The accuracy of the CCIR prediction technique is limited by terrain data, which simplifies its use and

Table 12
Comparisons — CCIR prediction/measurement for mixed paths

Band	Paths	Method A P/M Mean dB	Method A Standard deviation dB	Overland P/M Mean dB	Overland Standard deviation dB
I	682	0.5	7.2	− 2.5	7.4
II	682	−1.7	8.3	− 5.4	8.5
III	247	−5.9	9.1	−10.4	9.5
IV	1,439	0.8	11.8	− 4.3	13.0
V	641	0.4	11.5	− 4.0	10.2

hence enhances its popularity in international negotiations. However, such simplification inevitably affects its accuracy, and perhaps equally important it is imprecise in its definitions. This project has not investigated the past implications of these faults; constructive proposals for revision are more appropriate, and these are contained in Section 7 of this Report.

The basic concept of a field strength decay with distance curve, adopted in the CCIR texts, is useful, especially for international planning work, but this must be precisely defined. An obvious criticism is that the datum of the CCIR curves requires clarification. Based as they are, upon urban measurements at short ranges and on rural results at longer distances, the curves are only strictly applicable to calculations for such areas. Corrections which have been derived, such as those for the height of the transmitting antenna, for the effect of local and mean terrain and for receiving antenna height gain, have emerged from a variety of experiments and theoretical considerations; these have not always been correctly interpreted in terms of the original datum, or integrated. Also, as they have been progressively introduced over a period of many years, there are obvious signs of incoherence and incompatibility between various adjustments.

Statistical analysis is essential for the interpretation of a mass of data, but in Section 5D there are examples where this has led to oversimplification which has obscured important propagation features. The most obvious example here is to be found in the assessment of location variation. If closer examination had been possible, it would have revealed several significant factors which should be treated separately.

Apart from technical considerations, such as the apparent overlap between the functions of the Δh and θ corrections, confusion in the prediction also arises because of the layout of the present Section 5D. It would be logical to have a single prediction recommendation, regardless of the height of the receiving antenna, thus there would be no need for a separate Report to deal with mobile radio. It is acknowledged that there is a real difference between material appearing in a 'Recommendation' and a 'Report', but there seems to be a clear case to combine much of the material at present found spread over the four documents — Recommendation 370, Reports 239, 567 and 228. A great deal of useful information, describing the practical results of experiments and operational experience, is scattered throughout the Section; some is included in the texts, others listed in the references, but unfortunately this often adds to the general confusion. It only serves to blur the fundamental recommendations which should contain the reliable and proven information. An attempt should be made to review this valuable evidence so that it may be incorporated properly in any revision.

6.2 Comments on the BBC prediction method and approach to an improved CCIR method

As revealed by the results shown in Tables 6 and 8, the BBC prediction method is generally more accurate than that of the CCIR, assessed in terms of the scatter about the median prediction/measurement result. Having regard to the complexity of the program, however, and its demand for detailed terrain data, greater improvements might have been expected.

No attempt has been made in this project to investigate possible limitations in the BBC prediction program in any depth. This would have involved a detailed examination of what is already an extremely complex calculation; it is questionable whether further modification of this is warranted. The immediate objective is to propose a simpler technique of comparable accuracy to the BBC method, which might be offered as an international replacement for the present CCIR method. Adoption of a method, such as that used by the BBC for national planning, would require the availability of a detailed terrain data base on an international scale. Although such facilities do exist in some countries, they may be prohibitively expensive in others. It is unlikely, therefore, that a prediction of this complexity would prove internationally acceptable for some years.

However, BBC experience in broadcast planning work has shown that the extensive results of their prediction program encourage detailed analysis. This contributes to spectrum economy and coverage efficiency, factors not readily quantified by simple evaluation of the prediction/measurement equation. But as mentioned above, for international work a compromise is necessary. Also, more consideration has to be given to the accuracy of measurement and prediction discussed in Section 3.3. It is important not to lose sight of the statistics of reception.

It may be possible to devise a theoretically satisfactory propagation model which will predict field strength at any point in space, given adequate data describing the propagation path. But the amount of data required is likely to be enormous, and the cost-effectiveness of the process, at least for international frequency planning, must be questioned. It is also evident from this project that, in many instances, VHF/UHF propagation over the real surface of the earth, departs widely from some long-cherished optical ray theories; so a truly satisfactory prediction model, based upon these concepts, may continue to prove elusive.

Section 7 of this Report discusses the scope for improvement, concentrating on the essentially empirical approach. It observes the requirements for simplicity in concept using limited terrain data; it has the objective of proposing a method which is adequate for international frequency planning but given more data, could also be useful for detailed prediction.

7. POSSIBILITIES FOR IMPROVEMENT OF EXISTING CCIR METHOD

7.1 General

It has been previously observed that the use of field strength/distance curves has much to offer, and the proposals for an improved prediction technique now made are based upon this form of presentation.

Two distinct possibilities are considered here. The first would be for limited changes intended to improve the definition and precision of the existing curves of Recommendation 370. The present curves would be retained, but they would be more precisely defined. Modifications to the corrections would be proposed, including a revised terrain angle adjustment.

The second, and preferred proposal, is to produce an entirely new set of curves, which would eliminate completely the inconsistencies which are apparent at present. This approach involves a new method of defining terminal heights, and also demands a coarse data base which will permit an overall assessment to be made of the propagation path.

These proposals are now described in more detail.

7.2 Retention of the existing curves

As previously described, the existing curves, published in Recommendation 370, represent urban median measurements at short ranges, and rural median results at the longer distances. The amount of the discontinuity, which *may* occur at about 100 km and which has been 'smoothed' in the present curves, varies with frequency — it is the urban loss difference between the values U_A and R_A shown earlier in Fig. 4. It would be desirable to examine the long distance recording results, to confirm that the site variation factors which were determined for each experiment, support the terrain correction θ which has been established for the shorter distances. But, in the absence of this at present, it is assumed that this form of location correction is unaffected by distance. There is a potential discrepancy here, however, in that terrain corrections, determined for urban locations at short ranges, would have a different reference point to those for rural areas. Urban losses need to be taken into account, so the remarks below concerning clutter losses are relevant.

During the investigation discussed in Section 4.2, relating to modifications to the θ correction curves, it was observed that the greatest errors occurred at those sites producing values of θ within $\pm 1°$ of the horizontal, particularly in urban areas. This was attributed to the influence of urban clutter, and it was apparent that the θ curves were generally unreliable at these small angles within built-up areas.

A separate analysis of the data was carried out, in which the measurements were sub-divided into rural and urban. This revealed that the discrepancy between the two categories becomes significant at about $-3°$, but that it has disappeared at $+1°$. A negative terrain angle of 3° represents an obstacle of about 260 m in height at a range of 5 km. At 50 m distance, the height of the obstacle would of course be 2.6 m; imperceptible in terms of terrain data, taken into account in this prediction, but obviously the diffraction angles and resultant losses caused by nearby rooftops will often be well in excess of this in urban areas[9]. The need for a clutter loss correction for urban prediction is evident; this also introduces the influence of receiving antenna height gain. Related problems affecting the present CCIR prediction have already been outlined in the sub-section 6.1.2.

The effects of clutter loss and receiving antenna height gain are almost inextricably mixed in urban and suburban areas. The concept of proportional height gain, based on the ideal situation of an optical path over flat terrain, is disrupted by the presence of local obstacles, which create confused diffraction and reflection conditions. In such circumstances elevation of the receiving antenna will reduce the diffraction losses, and the field strength gain is more likely to be related to the Fresnel parameter ν, defining the ratio of the amplitude of the obstructed to the unobstructed wave under knife edge conditions. In typical situations, however, it is seldom possible to identify the ideal requirements for this prediction, although the comparatively isolated conditions of losses behind single, well-defined obstacles in urban areas have been studied and reported[13].

A pragmatic solution to a highly complex problem has been sought in CCIR Section 5D for attempting to deal with height gain and clutter losses at the receiving end. Much evidence has been examined and reported; not surprisingly, some confusion exists in the present texts. In putting forward proposals here, this information has been reviewed together with more recent results. Nearly 150 sources of measured data have been examined; but even so, the study of this height-gain feature has not yet exhausted all the references. The proposals made here are certainly preliminary.

Fig. 9(a) summarizes some of the published information which has so far been examined. In this Figure, the references for the evidence are given, but again it is emphasized that this represents a limited analysis of a large quantity of detailed experimental information. In all cases, average values of the results of an experiment are given, no indication of the overall range is provided. Much more analysis is required to obtain full benefit from all this evidence. In Fig. 9(a) urban, suburban and rural measurements are mixed, and a clearer picture emerges from Figs. 9(b) and 9(c), in which the results have been subdivided into two simple categories — urban/suburban, and rural. In this study the majority of the areas classified as urban contained buildings with roof lines at or above 10 m a.g.l., whereas suburban roofs are generally below this height. About 80% of the measurements so far examined are in the latter category.

Dealing firstly with Fig. 9(b), as expected, UHF results reveal substantially greater clutter loss than VHF in built-up areas. A log-linear relationship exists over the range 2 - 10 m a.g.l., although it must be remembered that these are average results. The range shown at 1.5 m from -12 to -22 dB is the result of comparing the values given in Figs. 1 and 2 of Report 567 with the equivalent predictions from Recommendation 370 for 10 m a.g.l. Apart from the lower limit of this, the one result which is completely isolated from the derived UHF curve shown in this Figure is that at 3 m a.g.l. suggested in Recommendation 370 for conditions at distances in excess of 100 km. The mass of evidence examined in this project covering path lengths of up to 120 km revealed no dependence on distance. So far, UHF results for heights greater than 10 m a.g.l. have not been examined.

VHF suburban/urban results approximate to the linear height gain curve below 10 m a.g.l. and exhibit less clutter loss. It is particularly interesting to note that the results at 7 m a.g.l. do not reveal the above average loss at these heights experienced at UHF, (see also sub-section 6.1.2), but the results at 5 m a.g.l. are significantly below the suggested curve. It may be that the effects of polarization are already influencing results, and further work is needed to define the exact course of the curve at these lower heights. For heights above 10 m a.g.l. the evidence suggests that the increase is greater than linear, but the amounts are small.

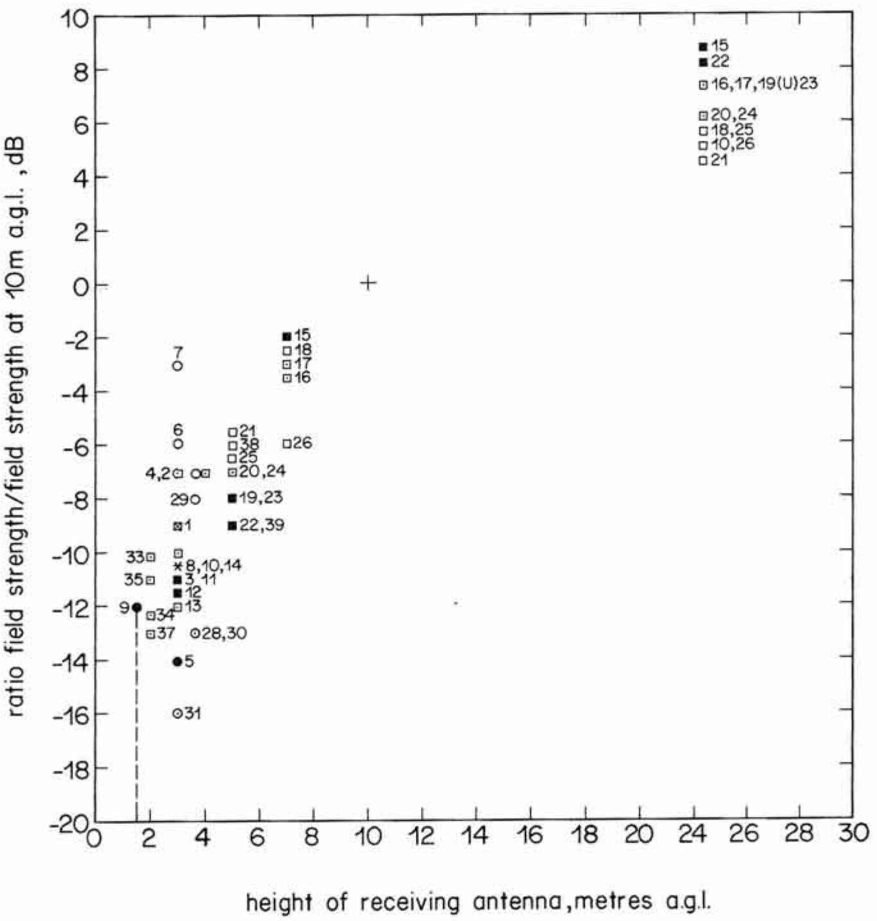
Fig. 9(c) gives the rural height gains, and these suggest frequency is having little influence. A linear height gain curve produces a reasonable compromise. Presumably, UHF results for heights above 10 m might reveal the effect of cancellation by the ground-reflected ray (having regard to the range of transmitting antenna heights covered in this study) but this has yet to be examined. Again, CCIR UHF results at 3 m, especially that for distances greater than 100 km, seem to be at variance with the general trend.

Two further observations must be made on the simple curves shown in Fig. 9. Firstly, little mention is made of polarization. Further work is required on this but a study undertaken some years ago on the quality of car radio reception[20] suggests little difference between horizontal and vertical polarization above 2 m a.g.l. Below that height, the latter offered substantial advantage, in terms of the mean amplitude of the signal. This reference quantified the advantage as approximately 5 dB at 1 m a.g.l.

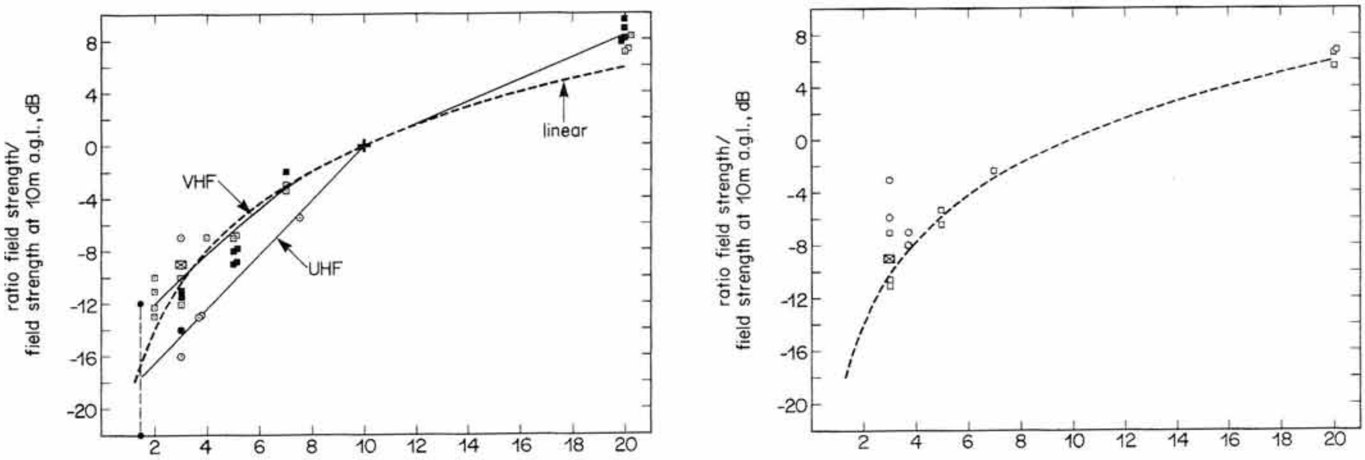
Secondly, Fig. 9 shows the results of measurement using a mix of non-directional and directional antennas. The results are adequate at this stage, although information does exist to permit further definition.

The provisional proposal made here, therefore, is that the simple curves of Figs. 9(b) and 9(c) could be used in conjunction with the existing propagation curves and the θ correction. Reception areas should be classified as ‘urban’ or ‘rural’, and for the former, the solid line curves of Fig. 9(b) would apply. In rural locations, the linear height gain curve of Fig. 9(c) would be used. The basic propagation curves should be re-defined as applying to ‘urban’ areas up to 100 km, and to ‘rural’ beyond that. The introduction of an urban loss constant could permit prediction of rural sites within 100 km, and urban locations beyond 100 km, but such a constant is not offered here. It could be obtained from existing results.

The three basic items of information — propagation curves, θ correction derived for a range of 5 km from the receiving site and receive antenna height gain curves — could constitute the main components of a revised Recommendation 370. The accompanying text would provide essential definitions, making particular reference to the significance of the prediction, and its range of application. The existing references to location variation and height gain, contained in Recommendation 370, would be replaced. In view of its confusion with the θ correction, the Δh parameter would be dropped, on evidence from the



Pt.	Bands	Category	Source	Ref.
1	I/II	All	CCIR Rec. 370	
2	III	Flat rural	"	
3	"	Urban or hilly	"	
4	IV/V	Suburban	"	
5	"	Urban	"	
6	"	Rural ⩽50 km	"	
7	"	Rural >50 km	"	
8	All	All	CCIR Rep. 239	
9	IV/V	Urban	CCIR Rep. 567	
10	All	All	Bell	14
11	III	Rural	DTI/GEC	15
12	"	Urban	"	"
13	"	Suburban	"	"
14	"	Rural	"	"
15	II	Flat, urban	"	"
16	"	Flat, urb/sub	"	"
17	"	Sloping, suburban	"	"
18	"	Sloping, rural	"	"
19	III	Urban	"	"
20	"	Suburban	"	"
21	"	Rural	"	"
22	II	Urban	"	"
23	"	Urban/suburban	"	"
24	"	Suburban	"	"
25	"	Rural	"	"
26	"	Sea (HP)	"	"
27	IV	Rural	BBC	16
28	"	Suburban	"	"
29	V	Rural	"	4
30	"	Suburban	"	"
31	"	Suburban	"	9
32	II	Suburban	"	17
33	"	Suburban (VP)	"	18
34	"	Suburban (HP)	"	"
35	"	Suburban	"	19
36	"	Suburban	"	"
37	"	Suburban	"	20
38	I	Rural	"	21
39	"	Urban	"	"



(b) VHF/UHF height gains in suburban/urban areas

(c) VHF/UHF height gains in rural areas

	VHF	UHF
Rural	□	○
Suburban	⊡	⊙
Urban	▪	●

Fig. 9 - Receiving antenna height gains.

UK measurements. Measurements made in more undulating terrain may support some additional correction, but it should be derived having regard to the effect of the θ adjustment.

If the Recommendation were revised in the manner outlined above, then not only would the prediction results be more accurate, the definitions of the process would have been considerably improved. However, a limited programme of modifications such as this would still not overcome serious flaws in the prediction, such as the unsatisfactory height above mean terrain parameter. For this reason, time has not been spent on quantifying in detail the benefits which would be achieved by these limited modifications. It is considered the main difficulties could only be removed by producing a completely new set of propagation curves, as now described.

7.3 The introduction of new propagation curves

As described in Section 6.1.3 of this Report, the height above mean terrain parameter is an inefficient means of determining the effect of height at the transmitting end. Yet it is obvious that at these frequencies terminal height is important for its ability to overcome obstacles and reduce diffraction losses. Whilst investigating the alternative of horizon distance, an interesting fact emerged which led to the postulation of a different approach, and the preparation of a program known here as 'PATHCAT'.

Measurements were grouped in terms of the category of the propagation path between the transmitting and the receiving antennas. Three categories were adopted:

Category 0 — line of sight
1 — one terrain obstacle
2 — > one terrain obstacle

Field strength/distance curves were plotted for all the measurements, subdivided into frequency bands and the three categories; the latter being determined using the 0.5 km terrain data base to assess each propagation path. It was clear that there was substantial similarity between the slopes of the resulting best fit curves, although there was considerable scatter of the individual results about the average values.

The process was clarified by concentrating on rural measurements, having terrain angles θ within $\pm 1°$ of zero; the result of plotting these field strengths as a function of distance for the appropriate categories of path is shown in Fig. 10. It will be seen that there is comparatively little difference between the gradients of these curves, not only for the various categories, but, surprisingly, also in terms of frequency. A likely explanation for the relative similarity is that, by using only those results obtained on level ground in open country, the effect of frequency gain is to counteract diffraction losses, because the latter will be caused by obstructions more than 5 km distant (the range for which the value θ is determined). Under these conditions, scatter about the average values, depicted by a best-fit curve, will be largely established by local clutter.

An indication of the scatter of the results about the average values is obtained from Table 13, in which mean errors and standard deviations of the rural measurements with $|\theta| < 1°$ have been computed. It will be seen that these are small, but the situation worsens considerably if measurements with higher values of θ are included, as shown in the same table. The need for a θ correction to deal with these larger angles is apparent.

The required correction could be derived using the values of Fig. 10 as a reference, but it was felt that because of the substantial similarity between them, they could be replaced by a single set of curves, representing all frequencies. Clearly this is a crude approximation, but in view of the simplification thereby achieved, it merited investigation. The resultant curves used for the study are shown in Fig. 11

Table 13
Comparisons — PATHCAT prediction/measurement
Rural results only

Frequency Band	$|\theta| < 1°$		$|\theta| > 1°$	
	P/M Mean dB	Standard deviation dB	P/M Mean dB	Standard deviation dB
I	+0.2	2.9	+0.6	5.4
II	+0.8	3.1	+0.5	6.8
III	−0.3	3.3	0	10.2
All VHF	+0.1	4.1	+0.3	12.2
All UHF	−0.7	6.8	−0.3	13.8

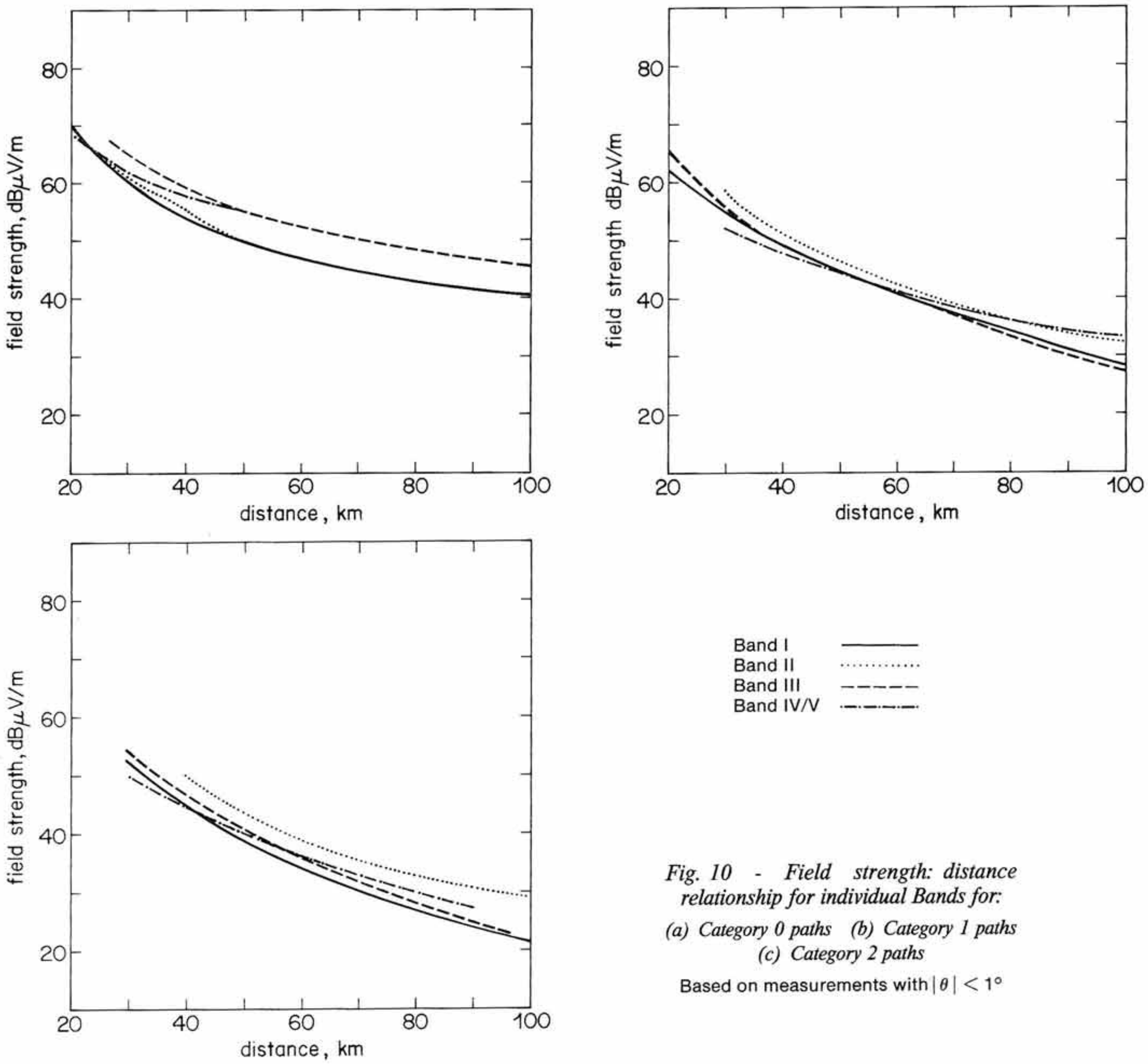


Fig. 10 - Field strength: distance relationship for individual Bands for:

(a) Category 0 paths (b) Category 1 paths
(c) Category 2 paths

Based on measurements with $|\theta| < 1°$

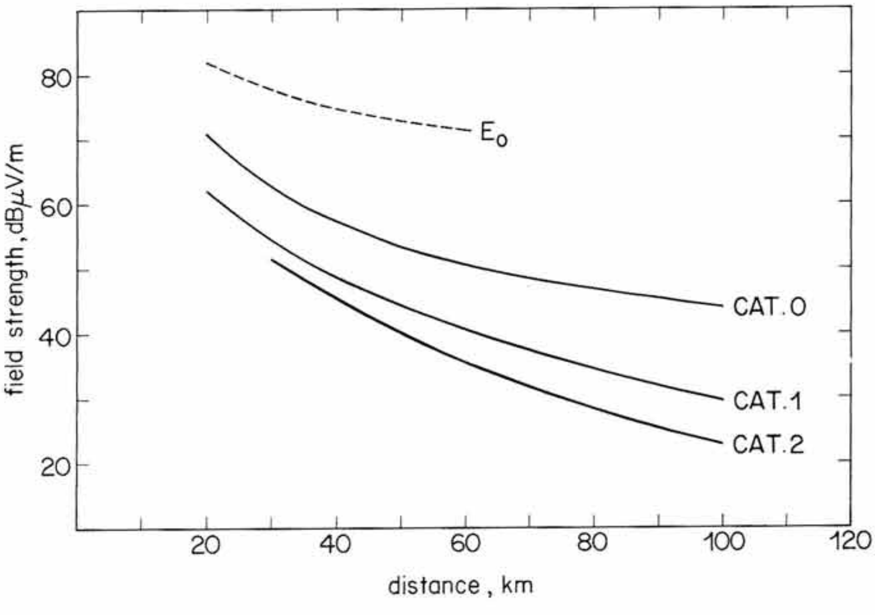


Fig. 11 - Field strength: distance relationships for all rural paths.

Based on measurements with $|\theta| < 1°$

demonstrating that on the evidence of these rural measurements the first obstacle creates the greatest diffraction loss, and these losses increase with distance. There is a very substantial difference between the theoretical free-space curve, and the results for the Category 0 condition.

Using the curves of Fig. 11 as reference, a sample of rural measurements was analysed to produce new θ correction curves based on the highest point of the terrain within 5 km of the receiving site. As expected, they revealed considerable frequency dependence.

It is emphasized that the investigation up to this point had been concentrated upon rural measurements — areas within which there is a substantial volume of evidence to show that linear height gain is general for the receiving antenna, at least for heights up to 40 m a.g.l. However, it was essential to include results from all environments, and to attempt predictions for the heights at which the measurements had been made. For this purpose, the corrections shown in Figs. 9(b) and 9(c) were also employed in this preliminary investigation.

The results of applying the simple propagation curves of Fig. 11, plus the height gain and revised θ corrections, are shown for a sample of 1,200 results in Table 14. The measurements used in this comparison are not those previously selected to determine the θ correction, and wherever possible measurements from different transmitting stations have been used. They were selected from rural and open sites in suburban areas, in order to minimize the confusing influence of high-density urban clutter, whilst providing some test of the height gain corrections.

Table 14
Accuracy of PATHCAT prediction

Frequency Band	Sample size	P/M mean (dB)	Standard deviation (dB)
I	400	−3.3	5.8
III	400	−1.1	8.0
V	400	−0.8	9.0

Comparing these results from an admittedly small sample with those of Table 6, it will be seen that the outcome is satisfactory, certainly as judged in terms of the standard deviations of the distributions. Indeed, the predictions compare quite favourably with the detailed BBC estimates, shown in Table 8. However, the variation in the P/M mean reveals a tendency to under-predict at the lower frequencies.

The development continued by investigating a much larger sample of measurements, resulting in a new set of θ corrections, as shown in Fig. 12. The following points are noted:

i) The curve deduced for Band III was also appropriate for Band V.

ii) Band IV results had not been separated in terms of the type of receiving location; however a separate study, described later, confirmed that the Band III/V curve is also applicable to Band IV.

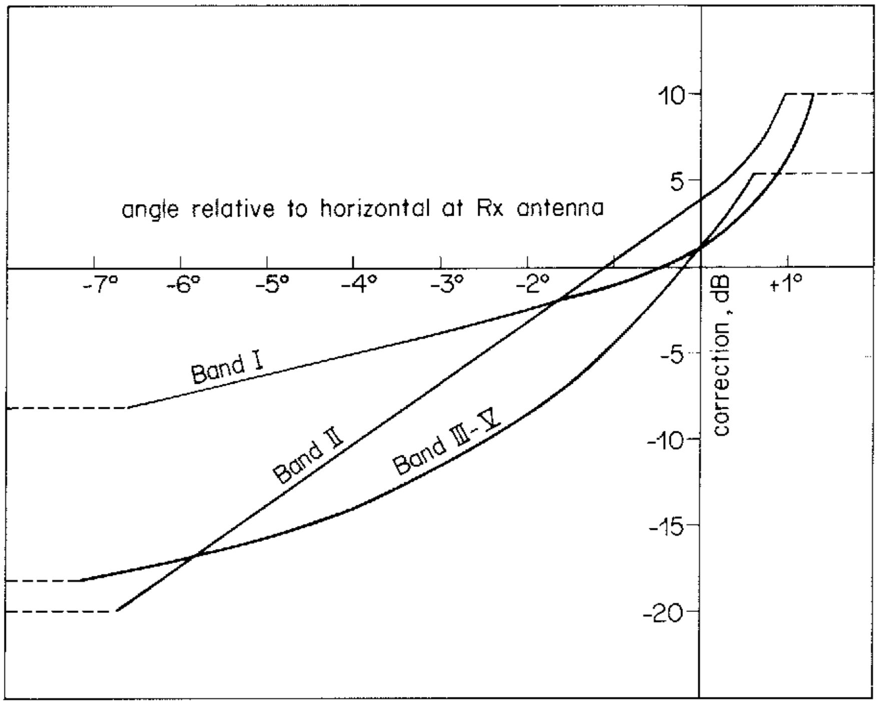


Fig. 12 - Receiving terrain angle correction for 5 km range (θ_5).

iii) The Band II curve appears inconsistent, but supports findings described elsewhere in this Report that, for comparable paths, Band II field strengths are higher than those in either Bands I or III.

iv) It is very likely that part of the difference between the results for the various Bands, at large negative angles of θ (i.e. in deeply diffracted areas), is attributable to receiving antenna directivity. For this reason, the curves cannot be extrapolated beyond the limits shown.

v) Similarly, the positive correction for angles above the horizontal only applies to results within the range shown.

Having thus optimized the θ correction curves from the provisional propagation curves of Fig. 11, this same large sample of rural measurements was then used to optimize the propagation curves for the various path categories using these θ corrections. It was found that the curves so obtained all had distance dependences closely agreeing to an inverse fourth-power law. The relationships resulting from the optimization are represented by:

Category 0 $E = 120 - 40 \log d$

Category 1 $E = 112 - 40 \log d$

Category 2 $E = 106 - 40 \log d$

where E is in dbμV/m for 1.0 kW ERP and d is in kilometres.

There was found to be one exception to these field strength/distance characteristics, this occurring for the UHF bands at distances less than about 15 km, for which the above curves tended substantially to overestimate the field strength. This short distance range represents an important category of service both in Broadcast and Mobile service applications, and it was considered important to take this discrepancy into account. This has been done on an empirical basis by assuming a linear relationship between field strength (in dB(μV/m)) and distance, for path lengths of less than 20 km. This modification should be considered as provisional and pending further investigation. There is insufficient VHF data available to determine whether this modification is also appropriate for these Bands.

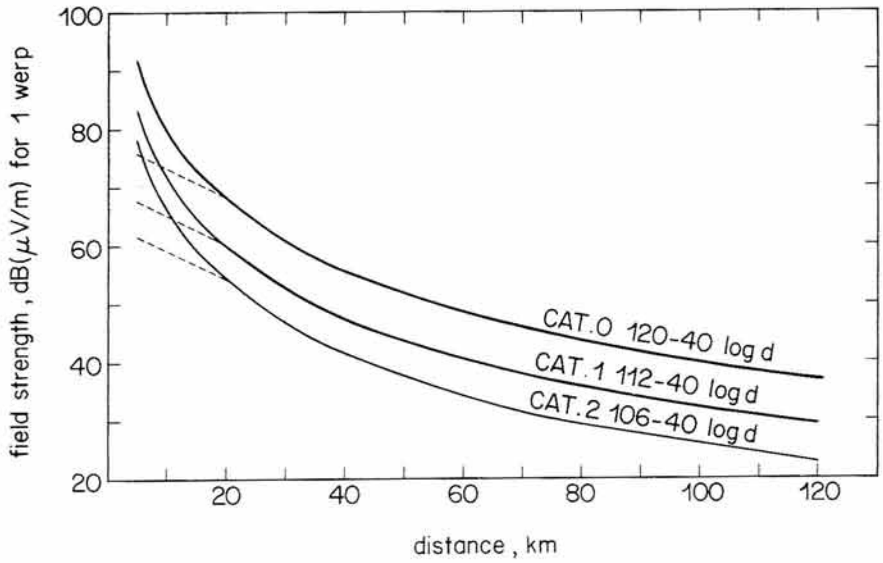
The propagation curves are indicated in Fig. 13.

The analysis of all the rural results, using the derived propagation curves and θ corrections, is shown in Table 15.

Table 15

Accuracy of PATHCAT prediction based on rural area measurements

Frequency Band	Sample size	P/M mean (dB)	Standard deviation (dB)
I	2962	0.7	6.6
II	1766	0.4	7.2
III	833	−0.9	8.0
V	1774	−1.8	8.7



extension below 20 km is for UHF only

Fig. 13 - Basic propagation curves of PATHCAT method.

Table 16
PATHCAT predictions for non-rural area measurements

Frequency Band	Sample size	P/M mean ratio (dB)	Standard deviation (dB)	Clutter loss (dB)
I	2980	1.4	6.5	0.8
II	5397	1.1	7.8	0.7
III	7140	−0.4	8.3	0.6
V	6514	0.5	9.7	2.3

Table 16 tabulates a corresponding analysis for the larger number of results of measurements for non-rural receiving locations, based on the same propagation and receiving angle curves. The difference between the mean values in Tables 15 and 16 can be considered to represent the mean value of 'urban loss'.

From the comparison between Tables 15 and 16 it may be deduced that:

i) For the VHF Bands, there is a difference of less than 1 dB between the results for the 'rural' and 'non-rural' receiving location classifications. Hence there appears little advantage in maintaining the distinction between rural and urban situations. This does not, of course, mean that the concept of a clutter loss is invalid for these Bands. A classification in terms of local building height and/or density might have yielded different results, and clearly this is a subject for further study.

ii) For Band V, there is a more clearly defined difference between the rural and non-rural results. Moreover, this may be somewhat greater than indicated, because the 'non-rural' results themselves contain a proportion which were not classified and thus will contain some 'rural' results.

Table 17 provides the results of an analysis taking account of all paths (i.e. rural + non-rural) including the Band IV results.

Table 17
PATHCAT predictions for all measurements

Frequency Band	Sample size	P/M mean (dB)	Standard deviation (dB)
I	5942	1.4	6.5
II	7163	1.1	7.8
III	7963	−0.4	8.3
IV	9828	1.1	10.6
V	8288	0	9.5

The process of optimization of the propagation curves and of the θ correction, has realised significant improvements in the P/M mean, compared with that initially obtained with the small sample, described in Table 14. There is a marginal deterioration in the standard deviation, to be expected in view of the large increase in the number of comparisons which have been made. However, detailed examination of the results for individual stations has revealed possibilities for further improvement; these are discussed in Section 7.5.

The results so far obtained, suggest that this comparatively simple approach, even in its present state of development, could provide an accuracy at least equal to that obtained using the existing CCIR technique, with the advantages that the prediction situation and conditions are precisely defined. This is based on substantial evidence that the major influences of terrain and frequency upon field strength can be determined from a simple appraisal of the overall propagation path, combined with a detailed analysis of the conditions within 5 km of the receiving site. Of course, this conclusion is reached on the basis of a sample taken from terrain typical of that found in North-western Europe; more extreme terrain conditions might increase the error. A limited examination of results obtained in severe terrain outside Europe suggests that this will not happen, although the measurement of multipath in areas of serious diffraction is a factor which must be taken into account. More work is required on this aspect.

The improvements described have been realised by taking more account of the terrain in the propagation path than is possible using the existing CCIR technique. However, it is desirable to quantify this improvement, assuming the same basic prediction is retained, but using different densities of terrain data. A two-stage facility would be attractive for international planning work — permitting the basic prediction to be used for work between countries; thus demanding a low-density data base, whilst offering greater precision for national development, for which more data might well be available. Under these circumstances there would be no need to standardize the nature of the additional data. The influence of terrain data density upon accuracy is discussed in the next section.

7.4 Prediction accuracy *v* Quantity of height data

The accuracy of any prediction method is influenced by the height data available to describe the unique features of each propagation path. However, the relationship between data density and accuracy is seldom made clear; this is an unfortunate omission having regard to the cost of such information. Examination of this feature has formed an important part of this project and some results are now described.

It is first necessary to concede that the PATHCAT results, described in the previous section, have been obtained using a density of terrain data which was probably greater than that needed for the existing CCIR prediction, although this is not certain. The classification of the paths has been determined using the 0.5 km data base; thus, on average, a minimum of about 100 heights will have been used by the computer to produce this information for each measurement/prediction site. In comparison, assessment of height above mean terrain for the CCIR prediction requires an analysis of conditions over only 12 km of path. If carried out thoroughly, evaluation of Δh requires a substantial amount of information, but in practice this is seldom undertaken in planning work. However, in this examination, this parameter and the θ corrections, for both 5 km and 16 km, have been accurately determined using the 0.5 km base.

Because the existing basic CCIR method makes little demand for terrain data, increasing the detail of the latter has little effect on its accuracy. It is not until the θ correction is applied that the significance of density becomes apparent — in the method of profile construction that was used, a reduction in terrain data density effectively flattens the terrain and reduces the influence of the adjustment. The error is particularly marked in the θ_5 condition. A similar result is obtained with the BBC prediction, which was optimized on 0.5 km terrain data and relies heavily upon an accurate determination of the profile. Table 18 demonstrates the effect of reducing the terrain data density. It may be seen that:

i) there is very little difference in values for the basic CCIR prediction without θ correction, indicating the minor effect of variations in effective height, and the Δh estimations,

ii) in all other cases, the reduction in density makes the P/M more positive and increases the standard deviation.

In practice, much depends upon the profile under examination. In flat or gently undulating terrain, reasonable accuracy can be achieved using a comparatively coarse data base. In contrast, rugged countryside demands greater detail.

Another relevant feature, is the accuracy of the present means of extracting profiles and other height data from the existing 0.5 km base. As mentioned earlier, a small part of this investigation was devoted

Table 18
Prediction accuracy v. Density of terrain data

Prediction	Terrain density					
	0.5 km		1.0 km		2.5 km	
	P/M dB	Standard deviation dB	P/M dB	Standard deviation dB	P/M dB	Standard deviation dB
CCIR (no θ)						
VHF	2.0	10.6	2.1	10.6	2.3	10.6
UHF	0.9	13.8	1.0	13.9	1.3	14.0
CCIR (with θ_{16})						
VHF	−2.7	7.9	−1.4	8.2	0.9	9.3
UHF	−3.0	10.9	−1.5	11.7	1.0	13.1
CCIR (with θ_5)						
VHF	−0.6	8.4	0.8	8.8	3.5	10.0
UHF	1.1	12.4	3.1	13.5	6.2	15.3
BBC						
VHF	2.7	7.1	4.1	7.5	6.6	8.5
UHF	−3.1	9.6	−1.3	10.7	1.0	12.5

Table 19
Comparison between receiving location heights derived from maps and those derived from the terrain data base

Station	Band	No. of samples	Mean discrepancy map: data bank (m)	Standard deviation (m)
Rowridge	I	1411	1.6	15.8
Wenvoe	II	3256	0.5	16.8
Emley Moor	III	1524	0.8	16.7
Winter Hill	IV	1475	−0.8	18.8

to comparing actual terrain heights, recorded at the time of measurement or subsequently, with those estimated by the computer, using its 0.5 km data base. The result of this comparison is shown in Table 19 for the surveys of four transmitters.

Having regard to the methods adopted in producing this base, and by examining a number of critical diffraction edges in a sample of profiles, it is estimated that fewer than 5% of the categorizations of path will be erroneous. In such cases, the error is likely to overstate the obstructions. Errors in deducing the CCIR parameters (height above mean terrain, Δh and θ) will have been negligible.

Of course, the crude categorization as used in the PATHCAT prediction, is not very demanding in terms of extreme accuracy in profile definition. For comparison with the results of Table 14, a data base was set up, in which the maximum height of the terrain within each 5 km square of a matrix covering England and Wales was stored; this was used for path categorization. The 1,200 predictions reported in Table 14 were re-examined, and it was found that identical path classification was achieved in 1,037 cases; of these, 149 overstated the obstructions. The results of the revised predictions are shown in Table 20, showing negligible change in the mean errors but some significant increase in scatter.

In the absence of a very detailed terrain data base and computer facilities, assessment of terrain conditions within 5 km of the receiving site can be a tedious process; but having regard to its significance in the types of prediction described here, it demands precision. Manual assessment requires the use of maps having a scale of not less than 1 : 50,000. Various techniques can be adopted, and special protractors have been devised to avoid the need to draw profiles.

Information concerning the effect of local clutter is also of interest here; until recently, the methods used to assess this have been relatively coarse. Various workers have produced classifications in order to predict losses due to 'land cover'[22 - 26], and much new information is now becoming available. With specific reference to the requirements of mobile radio, there is also increasing interest on the incidence of multipath (although this also affects broadcasting); means of quantifying these effects have been proposed[25, 27]. These developments are discussed in the next Section, which deals with possible improvements of the PATHCAT prediction which could enhance its precision, given more data to describe the terrain and land cover.

7.5 Further developments

The very substantial measurement and terrain data base which has been built up in this project, is a valuable basis for further work. From the work so far completed, promising avenues of additional study have been identified. Initially, this project is concentrating upon the UK measurements which have been processed, for which much additional data is already available. In due course, however, it will be essential to take more account of measurements which have been made available from other countries, in order to

Table 20
Accuracy of PATHCAT prediction
Comparison between results for 0.5 and 5 km data base

Frequency Band	Sample size	P/M Mean (dB)		Standard deviation (dB)	
		0.5 km	5 km	0.5 km	5 km
I	400	−3.3	−3.7	5.8	6.6
III	400	−1.1	−1.5	8.0	9.3
V	400	−0.8	−1.1	9.0	10.8

test the proposals which are emerging. A general requirement, which is becoming increasingly important, in view of the increased use of higher frequencies by terrestrial broadcasting and mobile services, is to extend the range of this type of prediction technique to cover the spectrum up to 12 GHz. Beyond this range, the increased effects of precipitation attenuation and gaseous absorption introduce factors not taken into account by this simple approach.

Developments are discussed under two main headings — firstly the basic propagation curves, secondly the detailed corrections.

7.5.1 The propagation curves

The field strength/distance curves of Fig. 11 and subsequently of Fig. 13, have been approximated from those in Fig. 10. The effects of frequency and several other important factors have been concealed in this process. Clearly, the exact nature of each propagation path is important here; i.e. the features of the ground profile, the distance of obstacles from each terminal, and the shape of diffraction edges. A separate examination is taking place, in which the individual ground profiles are being compared and grouped using a process of pattern recognition. From this, it is hoped to deduce a few simple parameters, which will permit the accuracy of the basic assessment of the field strength decay with distance, to be substantially improved.

In addition to clarifying the effects of frequency, it is expected that the examination of the overall path will produce substantial new evidence concerning the influence of polarization and ground reflection. Although obscured by the preliminary methods of the analysis so far used, these features are obviously important for certain types of propagation path. Receiving sites nominally within line of sight of the transmitting antenna are of particular interest.

The effect of fading has also been largely ignored so far, although as mentioned earlier where evidence of confusion in the measurements existed, these measurements were rejected. Some evidence exists within the UK from recordings made over path lengths which span the range from 50 to 200 km[28, 29]; closer analysis of these results is needed to bridge the gap between the service area measurements and those which have emerged from the substantial programme of long-distance studies. This work requires a clearer definition of the relationship between the site variation factors, which have been used for the long-distance measurements, and the terrain correction, a point discussed in Section 7.2 and dealt with again below.

The previous paragraph raises the question of abnormal propagation affecting the longer ranges. It must be emphasized, that the curves of Fig. 13 were derived using the measurements selected for this project; they take no account of paths exceeding 120 km in length. The tropospheric causes of temporal changes have not been considered here, although, as mentioned earlier, they were apparent at ranges as low as 30 km from the transmit antenna.

With most prediction methods, which take detailed account of terrain data in assessing the path losses (not those of Section 5D), the effects of abnormal propagation are simulated by decreasing the Earth's true curvature, so reducing the diffraction losses. In the case of the BBC program, for example, the effective Earth's radius is assumed, for overland propagation, to be multiplied by 1.33 for 50% time results, 2.2 for 5% and 4.5 for 1%. Higher multipliers are used for oversea propagation. Such an approach is largely supported by the measured evidence which is available and might be suitable for the PATHCAT prediction. However, there still exists a substantial gap in present knowledge concerning the relationship between the parameter 'percentage time' and the physical factors known to cause abnormal propagation. There is a requirement to relate the statistics of these, notably the refractivity gradient in the lower atmosphere, to those of field strength measurements over longer paths. In the absence of this type of information, means of quantifying temporal changes in the received signal have been considered, and methods need to be formulated for extending the range of the PATHCAT prediction which will improve both the accuracy and the definitions.

7.5.2 Local conditions

The PATHCAT approach hinges on the assumption that the received field is largely determined by conditions local to the receiving site; i.e., within a range of 5 km. Within this range, surface cover will be increasingly significant; means of describing this are being examined. In rural situations, the effect of vegetation is to increase both the scatter and attenuation of the received signal, and its influence has been described by several workers. Increased multipath has also been reported from certain areas. With all this evidence from previous experiments, the process is to reappraise rural measurements in detail, initially to determine the scale and importance of the problem. It may be of comparatively little relevance to the assessment of a television broadcast service area, but more significant to mobile radio and broadcast reception.

Building losses are clearly of considerable interest to all types of service, and a vast amount of evidence already exists. Here again, the first approach has been to re-examine the processed measurements obtained in this project, guided by the published results of other experiments. An obvious problem is that of defining the physical obstacles; whilst it is relatively easy to deduce some kind of simple statistical adjustment, to take account of different types of urbanization, what precision can the prediction achieve without excessive complication?

It is possible to get extremely detailed data, concerning the heights and shapes of buildings in many cities of the UK, and methods can be suggested for calculating losses over and around these obstacles. Many experiments have been reported in recent years identifying the losses to be expected behind various structures. As part of this project, a study of building losses was carried out in three cities in the UK, for which very detailed field strength measurements are available. But the results are complex and, having regard to the variation of field strength with location observed in such areas, influenced by factors which cannot be predicted; an investigation of this detail is most unlikely to be cost effective for routine work.

However, it is certainly possible to improve upon the crude means of taking account of clutter loss which has so far been used in Section 7.3 of this Report, namely the receiving antenna height gain curves. Information included from the three cities, mentioned in the previous paragraph, suggests that by simply subdividing urban areas into two categories — suburban and urban — improvements in accuracy can be achieved, although the results described in Section 7.3 suggest these may only be significant at the higher frequencies. Information of this nature is relatively easy to deduce from existing sources (in the UK). Further subdivision of the classification, namely to include a fourth category, described as 'dense urban' (containing buildings of more than four storeys), produced less significant advantages, and in view of the difficulties of definition, has been discounted to date. The directions of the streets, with respect to the direction of propagation, is a significant factor and one which might well be used in towns where 'block' development occurs. In the UK, this situation seldom exists.

Results described as 'urban' in the investigation which have formed the bulk of this project, would, under this classification, be regarded as 'suburban'. The majority of these measurements came from areas in which the roof line was in the range 7 - 10 m a.g.l. In these circumstances, the 10 m antenna was just clear of local obstacles for more than 90% of the samples. Comparison with measurements made in areas where the buildings consisted of three- and four-storeyed houses, revealed median differences from 4 dB at Band III, to 7 dB at Band V. Further increases in diffraction loss were apparent in the centres of the large cities, where there were several high buildings; but the situation was increasingly confused by multipath, as discussed later.

Examination of the terrain levels within towns and cities is also yielding more information about receiving antenna height gain and building losses. Closely examined in the three cities previously mentioned, this is providing much additional information concerning the terrain correction θ, and the relationship between urban and rural conditions.

Much information already exists describing the losses to be expected inside buildings and this will need to be considered with the evidence described above. Extension of the prediction facilities to cover all types of receiving location is essential, if the technique is to satisfy the requirements of both broadcasting and mobile radio interests.

More work leading to clearer definitions is required on two other very important features affecting reception and prediction, namely multipath and receiving antenna directivity. These are two factors which influence many of the studies described above and, where available, measurements made with different types of receiving antennas are being re-examined in detail. Multipath is a factor of major interest in wideband communication, and means of quantifying its effects have been devised. Some of these studies are relevant to the question of field strength prediction and the impact of this aspect will need to be reviewed. It is also hoped that this study will allow the assessment of the extent of the local standing wave to be more precisely defined — an important feature because it really establishes the limit of practicable prediction.

The substantial data base of measurements which has been built up in this project, provides a valuable foundation for further work of the nature described above. It is also permitting more fundamental studies to be carried out for investigating the relationships between these results and propagation theory based on optical laws. This work is of no immediate interest to the scope of Section 5D of CCIR Volume V, but in due course, useful contributions may emerge which could apply to other sections of the same volume. Adoption of any new prediction method would, of course, have a substantial impact on Section D of CCIR Vol V. This is discussed in Appendix 3.

8. CONCLUSIONS

The study described in this Report has examined a large quantity of VHF/UHF field strength measurements, the majority being made within the UK. Many of these were used in the construction of the original CCIR curves from which the existing prediction technique of Section 5D of CCIR Vol V developed.

The extent of the errors of the present CCIR technique has been evaluated and presented. The errors are substantial in some cases, and their sources have been identified. In addition, other inconsistencies have been demonstrated. One specific factor, is that the receiver terrain angle correction (θ) appears more valuable than the terrain roughness correction (Δh). The latter forms part of Recommendation 370 whereas the former is only contained in the associated Report 239. With the increasing importance being attached within the CCIR to recommendations, it would seem that, even if no other changes are made, the θ correction should be incorporated within the Recommendation. Another notable discrepancy of the CCIR curves is represented in Fig. 3(a), which indicates a marked tendency for the UHF curves progressively to underestimate field strengths with increasing path length.

Many of the problems with the existing CCIR method arise because the technique calls for little information concerning the nature of the propagation path. In the past, this was an attractive feature of the method, since such data was both rare and costly. This is still true, although, in a number of countries, comprehensive data bases are being acquired, which will permit the application of more detailed path loss techniques capable of greater accuracy. Nevertheless, the advantages of a system making limited demands for terrain data are likely to continue within the CCIR for many years.

Furthermore, the extent of the improvements which can be achieved by the use of more terrain data, has still to be evaluated. If the BBC program is taken as an example, the results demonstrated in this Report suggest that there is still room for improvement, but is is very doubtful if the present data base will be adequate for further development. A new approach with expensive new facilities might be required, and at this stage in terrestrial broadcast development, such investment may well not be merited. In any case, investigation of some of the basic propagation theories, using the data obtained in this study, suggests that such erudite methods may have little if any advantage over the empirical approach. Perhaps mathematically appealing, their errors are nevertheless as great, in some cases greater, than those inherent in more heuristic systems.

An important conclusion reached in this Report is that reasonable accuracy can be achieved with comparatively little information concerning the propagation path. This observation has led to the proposal for a new technique, employing a coarse data base capable of revealing important features in the path, but embracing an end correction which takes full acount of vital details close to the terminals. The accuracy of such a system has been demonstrated using the UK measurements, and it is considered that scope exists for further improvement.

Assuming that a new prediction technique might be agreed internationally, this would require substantial revision of CCIR Section 5D.

Finally, although the full potential has not been discussed in this Report, the data, which has been collated in this project over the past four years, offers a substantial resource for further examination of radio propagation at VHF and UHF.

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APPENDIX 1

Measurement Data Format

This is subdivided into four categories as indicated in Table A1.1. The first deals with transmitter information (T). The frequency of the transmission on which the measurements were made is always recorded; in the case of positive-modulated television systems this is usually that of the sound carrier. Corrections were made, at the time of measurement, to allow for any variation in the output power of the transmitter, and for any directivity of the transmit antenna. Following these adjustments, all the results have been reduced to a standard ERP of 1.0 kW, as described below.

For the receiver information (R), the location of each measurement has been identified by the national grid reference (NGR); the computer has been used to derive the latitude and longitude (this process was also employed for the transmitter location). The path length calculations were made using these polar co-ordinates. The height of each receiving site (R5) was obtained from maps or from the original measurement records, and was used as a check against the prediction produced using the terrain data base held in the computer (R6). The height of the receiving antenna (R7) was recorded; this was used in the designation of the receiving site category (R8).

It was decided that, where there was no local 'clutter' (buildings and trees) or its height was well below that of the antenna, then the site would be classed as 'rural'. Alternatively, a site was described as 'urban' where the height of the clutter was assessed to be near or above that of the antenna. It will be described in the text of this Report that most of these measurements were made in relatively densely populated areas, more properly described as 'suburban'. In most cases this information was obtained from the original measurement records or personal knowledge, occasionally it was derived from maps. The terrain 'eyeball' assessment (R9) is unique to Band III results and is the measuring engineer's opinion of the slope of the foreground in the direction of the transmitter.

For the measurement data (M), the measured field strength (M2) is that obtained at the receiving antenna height (R7); M3 has been derived by adding a linear height gain, to give a representative result of the situation at 10 m a.g.l. for those points where the M2 measurement was obtained at some lower height. This is a factor of importance which is discussed at length in the text. The M4 value has generally been calculated by the computer, using any correction required by the horizontal radiation pattern of the transmitter. In the processing of the measurements, any effects of fading over the longer paths were taken into account wherever this was possible. This was achieved by comparing repeated measurements — which were rejected if this revealed significant disagreement — or by checking against the results of simultaneous static recordings, where these were available.

All of the path data (P) was calculated by the computer, using the geographical co-ordinates for each site, the coastline map, and the terrain data base used by the BBC. This is based on a 0.5 km grid of the UK, and as mentioned above, a part of the investigation was to examine the accuracy of this data bank.

Table A1.1
Details of field strength data contained in computer files

1. Transmitter information (T)

T1 = Station name
T2 = National grid reference
T3 = Latitude
T4 = Longitude
T5 = Site height a.m.s.l. (metres)
T6 = Antenna height a.g.l. (metres)
T7 = Frequency (MHz)
T8 = Polarization
T9 = ERP (as quoted in measurement — to be corrected by HRP if required — see M4)

2. Receiver information (R)

R1 = Path number or name if relates to town median
R2 = National grid reference of point or centre of town
R3 = Latitude
R4 = Longitude
R5 = Site height a.m.s.l. of point or town centre (metres)
R6 = Site height a.m.s.l. derived from terrain data bank (metres)
R7 = Antenna height a.g.l. (metres)
R8 = Category: R = Rural where local clutter height $<$ R7
U = Urban where local clutter height $>$ R7
W = Wooded
R9 = Terrain 'eyeball': UH = uphill; DH = downhill etc. (Band III)

3. Measurement data (M)

M1 = Date/s of measurement
M2 = Measured field strength at R7 in dBμV/m
M3 = Derived field strength at 10 m a.g.l. in dBμV/m
M4 = M3 for 1 kW ERP

4. Path data (P) — derived from terrain data bank etc.

P1 = Path length (km)
P2 = Constitution: L = overland; S = oversea; M = mixed (%)
P3 = Category: 0 = line of sight
1 = obstructed (single obstruction)
2 = obstructed (more than one obstruction)
P4 = Height of transmitting antenna above mean terrain (metres)
P5 = Δh (metres)
P6 = Transmitting antenna horizon angle (α)
P7 = Receiving antenna horizon angle (β)
P8 = Receiving terrain clearance angle (θ), for 16 and 5 km

APPENDIX 2

Calibration Errors and Repeatability of Measurements

An error in the calibration of the equipment is most likely to produce a bias in subsequent results. To examine the extent of this error, a large number of measurements were made in an extensive UHF experiment conducted some years ago[30]. After a period of some days, the equipment was calibrated again and the measurements repeated, care being taken to ensure that the receive antenna was positioned at the same points during both series, and that transmission conditions were identical. Examination of the distribution of the differences between the first and second series then revealed a small change in the median, attributed to calibration error. Further checks confirmed this. Similar information from daily test runs, carried out during VHF surveys, has also been examined. The conclusion reached is that such errors are usually sufficiently small to be ignored.

In the UHF experiment, referred to in the previous paragraph, the effect of random errors arising during the measurement process, due to some operational lapse, e.g., in the use of the measuring equipment, was indicated by the standard deviation σ of the distribution between the first and second measurements. This was approximately 2 dB, the distribution being log-normal. From limited results obtained by comparing survey results at other frequencies, it would seem that operational errors are usually independent of frequency, although the use of a directional receiving antenna introduces the additional risk of measuring a reflection, rather than the direct signal. A study carried out during one of the early UHF surveys revealed that nearly one in five measuring sites in urban areas yielded a field strength value of a reflection higher than that of the direct signal. However, a much lower proportion — 3% — occurred in rural and suburban areas.

The use of a non-directional antenna means that enhanced field strengths are often measured in areas screened from the direct signal. In such circumstances the measurement of multipath components is unlikely to give a reliable indication of the quality of a complex wideband transmission.

For the analyses described in this Report, the measurements were normalized to an ERP of 1 kW using the best available information about transmitter power, feeder loss and antenna performance. Apart from the operational errors discussed above, errors can be introduced if the actual performance differs from the specification. For obvious reasons, this is difficult to check, but it is not considered that significant errors will arise from this cause except possibly in cases where a high degree of antenna directivity is involved.

APPENDIX 3

Impact of a New Prediction Method upon Section 5D

A3.1 The scope of Section 5D

Section 5D of CCIR Volume V deals with aspects of propagation in non-ionized media relative to the terrestrial broadcasting and mobile services. It recognizes that the planning of such services requires the prediction of field strength over many thousands of propagation paths. For this reason it proposes more pragmatic methods than are recommended for point-to-point links, which are to be found in Section 5E. Similarly, it does not involve any relatively complex assessment of the effects of the ground or the atmosphere, which are described in Sections 5B and 5C. Its approach to prediction is formulated on the basis of the statistical analysis of past measurements, resulting in a series of readily understandable curves and simple correction formulæ.

The Section contains nine Recommendations and Reports. Four of these, listed at the beginning of this Report, would be affected if a major revision of the prediction method, such as that described here, were to be introduced. Of the remainder, Recommendations 616 (Terrestrial Mobile Maritime Services) and 529 (Land Mobile Services) would also be implicated, because they refer to methods used in the four documents. Report 880 (Propagation in Special Environments) is not directly involved, although reception within buildings is obviously a matter of interest in both broadcast and mobile radio planning. Report 526 (Terrestrial Broadcasting Above

10 GHz) discusses propagation in a range of frequencies outside the scope of this Report — and it must be observed that current proposals being considered within the CCIR have not completely closed the gap from 1.0 to 10.0 GHz which exists at present. Further development of the prediction technique described here will take this into account by examining its application to measurements made at higher frequencies. In respect of the remaining document of Section 5D, no observations are offered here on Recommendation 528 (Aeronautical Mobile and Radionavigation Services), where propagation curves are based upon transmission loss predictions.

Obviously, a new prediction method would affect a substantial part of the text of the present CCIR Section 5D, and it would be an ideal opportunity to carry out a much-needed revision of the whole of the Section. The suggestions made here cannot deal with detail, but two proposals are outlined. The first suggests limited changes intended to improve the definition and precision of the existing curves of Recommendation 370. The present curves would be retained, but they would be more precisely defined. Modifications to some of the corrections would be proposed, including a revised terrain angle adjustment. The second, and preferred proposal, would be to introduce an entirely new technique — such as that identified in this Report — which would eliminate many if not all of the problems which have been identified.

Of course it is immediately acknowledged that the PATHCAT program is still being developed, and that it is based almost entirely upon UK evidence. It is essential to determine how this aligns with results elsewhere; an important prerequisite for both of these proposals would be to ensure that this was carried out. There is an enormous quantity of material currently referenced in the Reports of the existing Section 5D which demands closer examination. So far, much of this valuable international information has only achieved the status of a reference, these potential contributions must be taken into account in any revision.

An important feature common to both proposals made here, is that the prediction method described in Section 5D should be suitable for both broadcasting and mobile radio services.

The effects of the two proposals upon Section 5D are now outlined.

A3.2 Impact of limited changes

It is suggested that all material needed to carry out the prediction should be embraced within one Recommendation. This would contain:

a) the existing propagation curves of Rec. 370, redefined so that it is clear what they represent;

b) a correction for receiving environment, similar in concept to the terrain angle θ curve of Report 239, but redefined for a range of 5 km instead of 16 km;

c) a correction for receiving antenna height;

d) a single recommendation for mixed path calculation.

Existing information to be found in Recommendation 370 concerning location variation would be deleted, because the concept of log-normal distribution is only valid for certain limited conditions. Similarly, the use of the Δh correction would be reviewed, because of the evidence described in this report of its overlap with the θ adjustment.

Accompanying text would be included which describes the spatial and temporal variations, supporting the definitions mentioned in (a) above. Information concerning the extent of local standing wave variation would also be supplied, because this is a variable which can seldom be defined exactly and which complicates the prediction of field strength at a precise point in space. It therefore sets the limit of accuracy of a practicable prediction method.

The improvements which can be achieved are limited by the retention of the existing propagation curves, and by the amount of data available for the prediction. Because these curves make comparatively little demand for terrain data, and their accuracy is thereby limited, provision of enormous detail describing the receiving environment offers comparatively little improvement. Thus there would be no merit in overcomplicating the receiving environment and antenna height corrections. The proposal here, therefore, is to limit prediction conditions to two simple categories — urban and rural.

However, a great deal of evidence now exists concerning the effect of the environment in the vicinity of the receive antenna, and the relationship between results inside and outside buildings. It is suggested this evidence is contained in a separate report within Section 5D, which would define the effects these factors could have upon the field strength which has been predicted using the Recommendation. Similarly, this report would contain a statement concerning the influence upon the accuracy of the prediction of the density of terrain data which is employed.

The scope of the proposed Recommendation and Report would encompass much of the information presently contained within Rec. 370, Reports 239 and 567. It is suggested that a further Report should be added, fulfilling more precisely the rôle at present somewhat inadequately occupied by Report 228. Nominally this deals with measurement, but it also discusses presentation. It is at present confined to broadcasting. To make it useful, and relevant to a revised Section 5D, it is suggested its scope should be extended to include mobile radio. It should distinguish between the prediction/measurement of field strength, coverage, and presentation. In respect of measurement, certain basic information contained in the texts of Section 5A, notably Report 227, should be referenced. However, the nature of the service under study — radio or television broadcasting, or mobile radio — will each require different techniques of assessment and description, and these should be outlined. More specialized aspects might be referred to the texts of Study Groups 8, 10 and 11.

A3.3 Impact of a new prediction proposal

Assuming the basis of the new prediction is similar to that of the PATHCAT proposals, i.e., a set of field strength/distance curves, then the overall layout of a new Section would be substantially similar to that described in A3.2. It would consist of a basic Recommendation, a supporting Report, and a Report describing methods of coverage analysis and presentation.

As before, the basic Recommendation would consist of the curves, plus the appropriate corrections. This time, however, the abandonment of the height above mean terrain concept used in Recommendation 370 would mean that the number of curves would be limited to the minimum of three suggested in the Pathcat approach. In its present state of development, the technique envisages greater precision as more evidence describing local conditions is made available to the calculation, a process of increasing complexity. However, the basic curves, providing an indication of the average decay of field strength with distance for the various categories of path, would be substantially simpler than those in the existing Recommendation 370, and on the basis of evidence presented in this report they are as accurate. They would satisfy many of the demands for international planning purposes.

It is virtually certain that any new method, including the PATHCAT approach, would demand more terrain data than is needed for the application of the present Recommendation 370, and the evidence presented in Section 7.4 of this Report is relevant in this context. As proposed in A3.2, the complementary report in a revised CCIR Section 5D would describe this information, and its influence in determining prediction accuracy; it would also include the details concerning clutter data.

Similarly, a second Report would be included and, as before, modify the present Report 228 and extend its scope.

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